

22104-H001-R0-00

CR - 134144

FINAL REPORT

FUNCTIONAL REQUIREMENTS FOR ONBOARD MANAGEMENT OF SPACE SHUTTLE CONSUMABLES

VOLUME I

CONTRACT NAS 9-12944

Prepared For

Mission Planning And Analysis Division
National Aeronautics And Space Administration
Lyndon B. Johnson Space Center
Houston, Texas

(NASA-CR-134144) FUNCTIONAL REQUIREMENTS
FOR ONBOARD MANAGEMENT OF SPACE SHUTTLE
CONSUMABLES, VOLUME 1 Final Report (TRW
Systems Group) 107 p HC \$7.50 CSCL 22B

N74-13589

Unclas
G3/31 24860

TRW
SYSTEMS GROUP

FINAL REPORT

FUNCTIONAL REQUIREMENTS FOR ONBOARD
MANAGEMENT OF SPACE SHUTTLE CONSUMABLES

VOLUME I

Prepared for
Mission Planning and Analysis Division
National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas


Contract NAS 9-12944

Prepared by:

P. J. Graf
H. A. Herwig
L. W. Neel

16 November 1973

Approved by:


L. W. Neel, TRW Study Manager

ACKNOWLEDGEMENTS

In addition to those who have worked throughout the study and have been the principal contributors to this report, valuable contributions have been made by numerous other individuals who have provided their ideas and critiques of the information presented herein. All cannot be named, but some of those deserving special mention are listed below:

ECLSS: M. R. Reumont
J. G. Torian

Propulsion: R. K. M. Seto
T. J. Walsh

RCS: R. D. Miller

FCCS: R. A. Mintz

Software: R. F. Jank
J. R. Morrison

Instrumentation: R. A. Kaminskis

CONTENTS

	Page
1. INTRODUCTION	1
2. STUDY OBJECTIVES	3
3. METHOD of APPROACH and PRINCIPAL ASSUMPTIONS	4
3.1 Study Approach	4
3.2 Principal Assumptions	6
4. SUMMARY of RESULTS	7
4.1 Major Study Conclusions	7
4.2 General Concepts Development	7
4.2.1 Minimum Onboard Capability Concept	11
4.2.2 Intermediate Onboard Capability Concept	11
4.2.3 Advanced Onboard Capability Concept	14
4.2.4 Advanced Onboard Capability with Automatic Replanning Concept	14
4.3 Shuttle Consumables Management Concept	14
4.4 Functional Areas Defined for Consumables Management System	17
5. TECHNICAL DISCUSSION	20
5.1 Consumables Management Review	20
5.1.1 Apollo Consumables Management Review	20
5.1.2 Aircraft Consumables Management Review	32
5.2 Consumables Management Study Guidelines	38
5.2.1 Shuttle Specific Consumables Management Guidelines	39
5.2.2 General Consumables Management Guidelines	42
5.3 Consumables Management Concepts	45
5.3.1 Concept Description	47
5.4 Concept Evaluations	57
5.4.1 Software Requirements	57
5.4.2 Hardware Requirements	58
5.4.3 New Technology Requirements	58
5.4.4 Mission Flexibility	59
5.4.5 Crew Workload	60

CONTENTS (Continued)

	Page
5.4.6 Crew Training Requirements	61
5.4.7 Consumables Management System Accuracy	61
5.5 Shuttle Consumables Management Concept	62
5.5.1 Consumables Management System Operation	66
5.5.2 Shuttle Subsystem Consumable Management Description	70
5.6 Advanced Concept Features	78
6. FUNCTIONAL REQUIREMENTS	82
6.1 General Consumables Management System Functional Requirements	82
6.1.1 Design Goal	82
6.1.2 Launch Readiness Checkout and Monitoring	82
6.1.3 Onboard Mission Operation Support	83
6.2 Auxiliary Power Unit (APU) Consumable Management Functional Requirements	83
6.2.1 Design Goal	83
6.2.2 Launch Readiness Checkout and Monitoring	83
6.2.3 Onboard Mission Operation Support	84
6.3 Environmental Control and Life Support System (ECLSS) Consumable Management Functional Requirements	84
6.3.1 Design Goal	84
6.3.2 Launch Readiness Checkout and Monitoring	84
6.3.3 Onboard Mission Operations Support	85
6.4 Fuel Cell and Cryogenics Storage (FCCS) Consumables Management Functional Requirements	86
6.4.1 Design Goal	86
6.4.2 Launch Readiness Checkout and Monitoring	86
6.4.3 Onboard Mission Operation Support	87
6.5 Main Propulsion System/External Tanks (MPS/ET) Consumables Management Functional Requirements	87
6.5.1 Design Goal	87
6.5.2 Launch Readiness Checkout and Monitoring	88
6.5.3 Onboard Mission Operations Support	88

CONTENTS (Continued)

	Page
6.6 Reaction Control System/Orbital Maneuvering System (RCS/OMS) Consumables Management Functional Requirements	88
6.6.1 Design Goal	88
6.6.2 Launch Readiness Checkout and Monitoring	89
6.6.3 Onboard Mission Operations Support	89
6.7 Consumables Management System/Orbiter Avionics Systems Functional Requirements	90
6.7.1 Mission Data Information Management	90
6.7.2 Ground Command and Data Link Interface	90
6.7.3 Display and Control	90
6.7.4 Data Processing and Software Support	91
6.7.5 Instrumentation Software	91
6.7.6 Guidance Navigation and Control Software	91
6.8 Consumables Management System/Ground Support System Functional Requirements	91
6.8.1 Ground Mission Operation Support	91
7. STUDY LIMITATIONS	93
8. RELATIONSHIP to other EFFORTS	94
9. SUGGESTED ADDITIONAL EFFORT	96
10. REFERENCES	97

FIGURES

	Page
Figure 3-1 Study Approach	5
Figure 4-1 Relationship of Consumables Management Functions to the Defined Functional Modules	10
Figure 4-2 Minimum Onboard Capability Concept	12
Figure 4-3 Intermediate Onboard Capability Concept	13
Figure 4-4 Advanced Onboard Capability Concept	15
Figure 4-5 Advanced Onboard Capability Concept with Automatic Replanning	16
Figure 5-1 Concept Number 1 Block Diagram	49
Figure 5-2 Concept Number 2 Block Diagram	53
Figure 5-3 Concept Number 3 Block Diagram	55
Figure 5-4 Concept Number 4 Block Diagram	56
Figure 5-5 Prepermission Analysis and Evaluation Sequence	67
Figure 5-6 Inflight Monitoring and Evaluation Sequence	68
Figure 5-6 Inflight Monitoring and Evaluation Sequence (Continued)	69
Figure 5-7 Inflight Mission Revision Sequence	71
Figure 5-7 Inflight Mission Revision Sequence (Continued)	72
Figure 5-7 Inflight Mission Revision Sequence (Continued)	73
Figure 8-1 Relationship of Consumables Management to Various Flight Operations Phases	95

TABLES

		Page
Table 4-1	Summary of Shuttle Consumables Management Features . . .	18
Table 4-2	Summary of Shuttle Concept Features	19
Table 5-1	Control and Propulsion Subsystems Summary	22
Table 5-2	Electrical and Environmental Subsystems Summary	23
Table 5-3	Commercial Carriers Consumables Management Summary . . .	33
Table 5-4	Candidate Consumables Management Concepts	48
Table 5-5	Shuttle Consumables for Management	63
Table 5-6	Relation of Shuttle Consumables Management to General Concept	65

LIST OF ACRONYMS

AH	Ampere Hour
ABES	Air Breathing Engine System
ABPS	Air Breathing Propulsion System
AIDS	Airborne Integrated Data System
APS	Ascent Propulsion System
APU	Auxiliary Power Unit
C&W	Caution and Warning
CM	Consumables Management
CM	Command Module
CMS	Consumables Management System
CPD	Crew Procedures Division
CRT	Cathode Ray Tube
CSM	Command Service Module
DPS	Descent Propulsion System
ECLSS	Environmental Control and Life Support Subsystem
EMAC	Energy Management Analog Computer
EPS	Electrical Power Subsystem
ET	External Tank
FAR	Federal Aviation Requirements
FCCS	Fuel Cell and Cryogenic Storage
FCD	Flight Control Division
G&NS	Guidance and Navigation Subsystem
JSC	Johnson Spacecraft Center
LiOH	Lithium Hydroxide
LM	Lunar Module
MADAR	Malfunction Detection, Analysis and Recording
MED	Manual Entry Device
MMH	Monomethylhydrazine
MPAD	Mission Planning and Analysis Division
MPS	Main Propulsion System
OIS	Operational Instrumentation System

LIST OF ACRONYMS (Continued)

OMS	Orbital Maneuvering System
PVT	Pressure-Volume-Temperature
RCS	Reaction Control Subsystem
RFP	Request for Proposal
SM	Service Module
SRM	Solid Rocket Motor
TBD	To Be Determined
T/M	Telemetry Measurement

1. INTRODUCTION

This report documents the results of the study conducted under Contract NAS 9-12944, "Functional Requirements for Onboard Management of Space Shuttle Consumables." The study was conducted for the Mission Planning and Analysis Division of the NASA Lyndon B. Johnson Space Center, Houston, Texas, between 3 July 1972 and 16 November 1973.

The overall study program objective was two-fold. The first objective was to define a generalized consumable management concept which is applicable to advanced spacecraft. The second principal objective was to develop a specific consumables management concept for the Space Shuttle vehicle and to generate the functional requirements for the onboard portion of that concept.

Consumables management is the process of controlling or influencing the usage of expendable materials involved in vehicle subsystem operation. The subsystems and related consumables selected for inclusion in the consumables management system are:

- Propulsion
 - a. Monomethylhydrazine
 - b. Nitrogen Tetroxide
 - c. Liquid Hydrogen
 - d. Liquid Oxygen
- Power Generation
 - a. Cooling Water
 - b. Hydrazine
 - c. Hydrogen
 - d. Oxygen
- Environmental and Life Support
 - a. Ammonia
 - b. Biocide
 - c. Lithium Hydroxide
 - d. Nitrogen
 - e. Oxygen
 - f. Water

The report consists of two volumes. Volume I presents a description of the study activities related to general approaches to developing consumable management concepts for advanced spacecraft applications and functional requirements for a Shuttle consumables management concept. Volume II presents a detailed description of an onboard consumables management concept proposed for use in the Space Shuttle.

2. STUDY OBJECTIVES

To accomplish the overall study objectives of defining a generalized consumable concept, and a Shuttle specific concept, the study included three primary objectives.

First, a number of different consumables management concepts were to be developed that offered a wide range of division of capability between the ground mission support complex and the onboard system. The management functions assigned to the onboard system were further investigated in order to determine which functions should be performed automatically versus which functions should be performed manually by the crew.

The second objective was to select a candidate concept for use in managing the Space Shuttle consumables by determining all of the consumables which require management, ascertaining the operational requirements affecting selection of a management technique, and selecting appropriate features of the previously developed concepts for managing the Shuttle consumables.

The third objective was to define a comprehensive set of functional requirements which may be used to initiate a design study for the onboard consumables management system.

3. METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

3.1 STUDY APPROACH

The study approach was designed to proceed from a general study to a specific application of consumables management to the Shuttle. The phases of the study plan are described below and shown in Figure 3-1.

- a. Review Consumables Management Techniques - The areas of investigation included space program mission planning and flight support, aircraft flight planning and operations, and aircraft subsystems performance monitoring for previous space and aircraft programs. The techniques which showed potential application to advanced space programs were applied later in the study to development of consumables management concepts.
- b. Define Concept Development Guidelines - General guidelines were developed which established both goals and constraints for the concept development phase of the study. These guidelines were weighted toward shuttle program objectives.
- c. Develop Consumables Management Concepts - Several different techniques were developed for performing consumables management. The techniques varied as to the degree of consumables management performed onboard the vehicle and also to the degree of automatic performance of onboard functions.
- d. Select Shuttle Consumables Management Concept - A Shuttle concept was selected under joint action by TRW and JSC that applied Shuttle operational requirements and design features as criteria in selecting appropriate techniques from the general previously developed concepts.
- e. Perform Shuttle Concept Study - A detailed study was conducted to define more specific details of the Shuttle concept. The types of onboard software functions were defined in detail as were the various interfaces with the software.

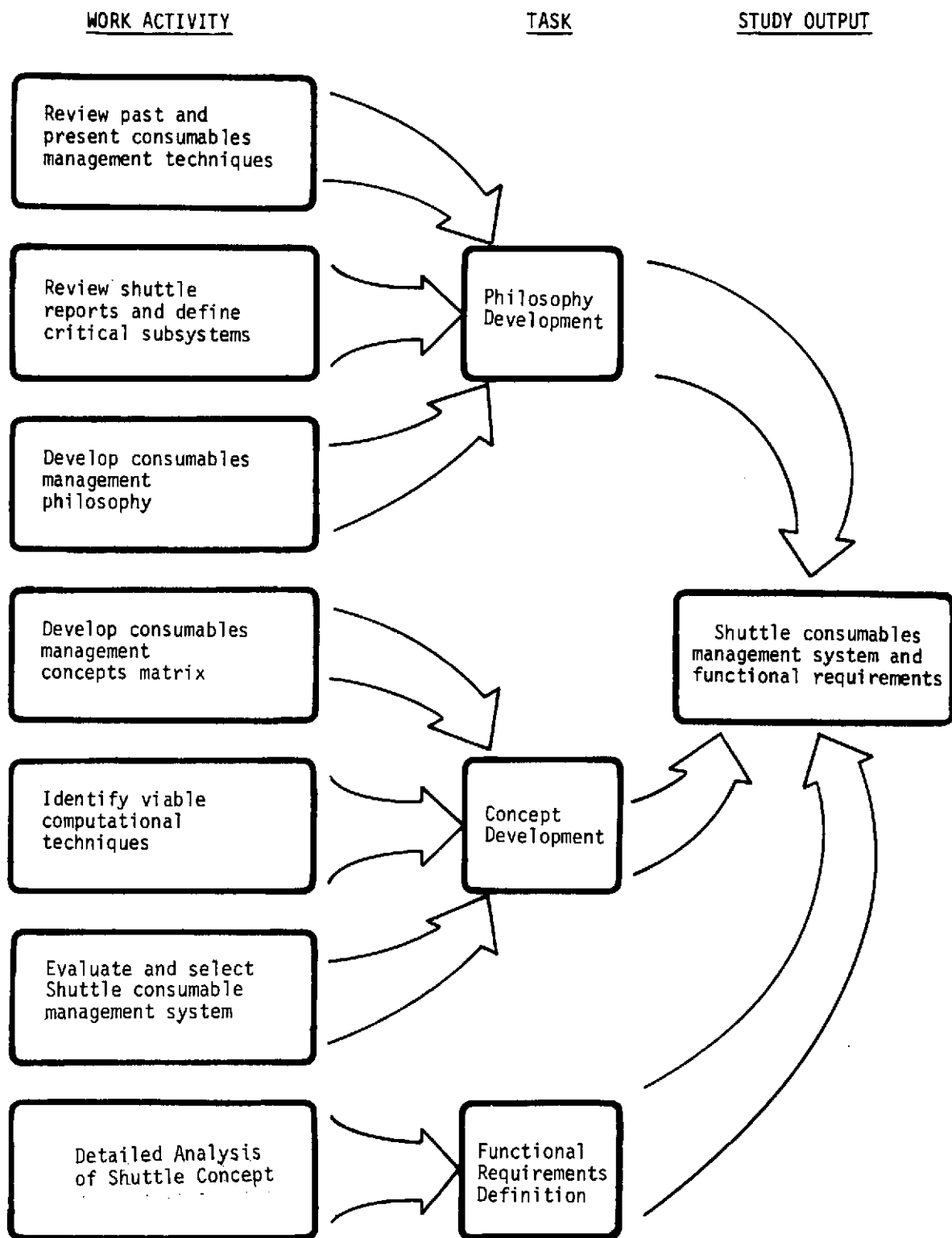


Figure 3-1 Study Approach

- f. Identify Functional Requirements for the Shuttle Concept - Results from the detailed study of the Shuttle concept were used to develop a set of functional requirements for the onboard consumables management system. The approach taken was to make the requirements as specific as possible at the present stage of Shuttle subsystems development.

3.2 PRINCIPAL ASSUMPTIONS

A number of assumptions were defined, under JSC direction, in order to evaluate the range of consumables management capability to be included in the concepts considered under this study. Shuttle requirements were of primary importance in forming the assumptions. Therefore, concept development was restricted to techniques which were both feasible and acceptable for present applications.

The assumptions used as the principal study guidelines were:

- Concepts should remain within bounds of presently envisioned technical and operational techniques.
- Concepts development procedures should be generally useful for developing a consumables management concept for any advanced space vehicle.
- Development of the Shuttle concept should be based on program goals and operational flight requirements (i.e., development flight requirements are not considered as constraints).
- Emphasis should be placed on detailed study of special requirements, either hardware or software, required to implement the Shuttle concept.

4. SUMMARY OF RESULTS

The objectives of the study have been completed. The major outputs are:

- Development of general concepts for performing consumables management
- Development of concepts for managing each of the Shuttle consumables
- Development of the functional requirements for the Shuttle onboard consumables management concept

An overview of the results are presented in this section. The supporting details are presented in Section 5., Technical Discussion. The functional requirements for the Shuttle concept are presented in Section 6.

4.1 MAJOR STUDY CONCLUSIONS

Several conclusions of major importance which resulted from the study are presented below.

- The Shuttle consumables management concept is based on standard aircraft and spacecraft technology and, therefore, represents a minimum risk development effort. The concept relies on techniques similar to those used on Apollo and was developed as a highly flexible system with minimum ground support requirements.
- The selected concept provides capability which allows the crew to perform a large number of consumables management and diagnostic activities with a minimum impact on onboard hardware and software requirements.
- The Shuttle consumable management concept was developed in a manner which can be implemented according to an orderly phased development plan.

4.2 GENERAL CONCEPTS DEVELOPMENT

Because the shuttle subsystems design concepts and the operational philosophy were changing rapidly during the study time frame, an effort was made to produce a general consumables management concept which could

be easily adapted to the final shuttle configuration. To accomplish this objective, the general consumable management concept was divided into functional units of capability, or functional modules, which in turn can be arranged to fit current shuttle requirements.

Reduction of the consumables management process to its basic functions contributes to a better understanding of the activities involved. The basic functions, which follow, may be either ground or onboard activities and may be either automatically or manually performed.

- a. Monitoring - The measurement, processing, and observation of subsystem parameters which are indicative of consumables usage. The primary parameters of interest are consumable quantity and usage rate measurements, but additional monitoring is frequently required to adequately ascertain usage characteristics.
- b. Evaluation - The comparison of monitored data to a reference, such as a predicted usage profile, to determine the deviation between actual and reference values.
- c. Assessment - The determination of causes of deviation of actual usage from predicted conditions, impact of the deviation on the remainder of the mission, and options available to correct for the deviations.
- d. Corrective Action - The measures taken to correct or control the usage of consumables. Action may include measures such as reconfiguring subsystems, replanning mission activities, or modifying operational procedures.

These four basic functions involved in performing consumables management formed the basis for defining modules or groups of activities which were considered candidates for software implementation. These functional modules may be used to construct consumables management concepts by different arrangements of ground and onboard functions and by different degrees of automatic or manual performance. The consumables management functional modules consist of:

- a. Monitoring Module - The activities associated with converting and presenting subsystem sensor data to provide consumables status data are included in this module. Consumables status information includes quantity remaining, quantity used, and quantity usage rates.

- b. Consumables Prediction Module - The functional activities associated with this module include the conversion of mission flight plan data into predicted consumables usage profiles.
- c. Inflight Consumables Prediction Module - The functional activities of this module are similar to those of the Consumables Prediction Module except that this module provides revised consumables usage predictions based on mission revisions.
- d. Evaluation Module - The functional tasks performed within this module includes comparison of actual consumables status with the predicted consumables quantities.
- e. Constraint Module - Testing both measured and calculated consumables parameters against predetermined limit values is the function performed within this module. The specific parameter to be tested for constraint violations is dependent on the particular consumable involved. Typical parameter checks in the constraint module will be consumable usage rates, difference between actual and predicted usage values, and minimum acceptable values for predicted end-of-mission quantities remaining.

The modules are related to the consumable management process as shown in Figure 4-1.

The functional activities just described are familiar spacecraft operations such as mission control activities, crew activities, or a combination of the two. The emphasis of this study was to determine the activities best performed onboard the vehicle and to determine the feasibility of implementing in the onboard software these functions which assist the crew in managing consumables usage. Various combinations of ground/onboard capability form the consumables management concepts which were considered in this study.

General concepts for performing consumables management were constructed by using the functional modules as building blocks to provide varying degrees of onboard and ground capability for executing the consumables management activities. The concepts discussed in the following sections provide steps

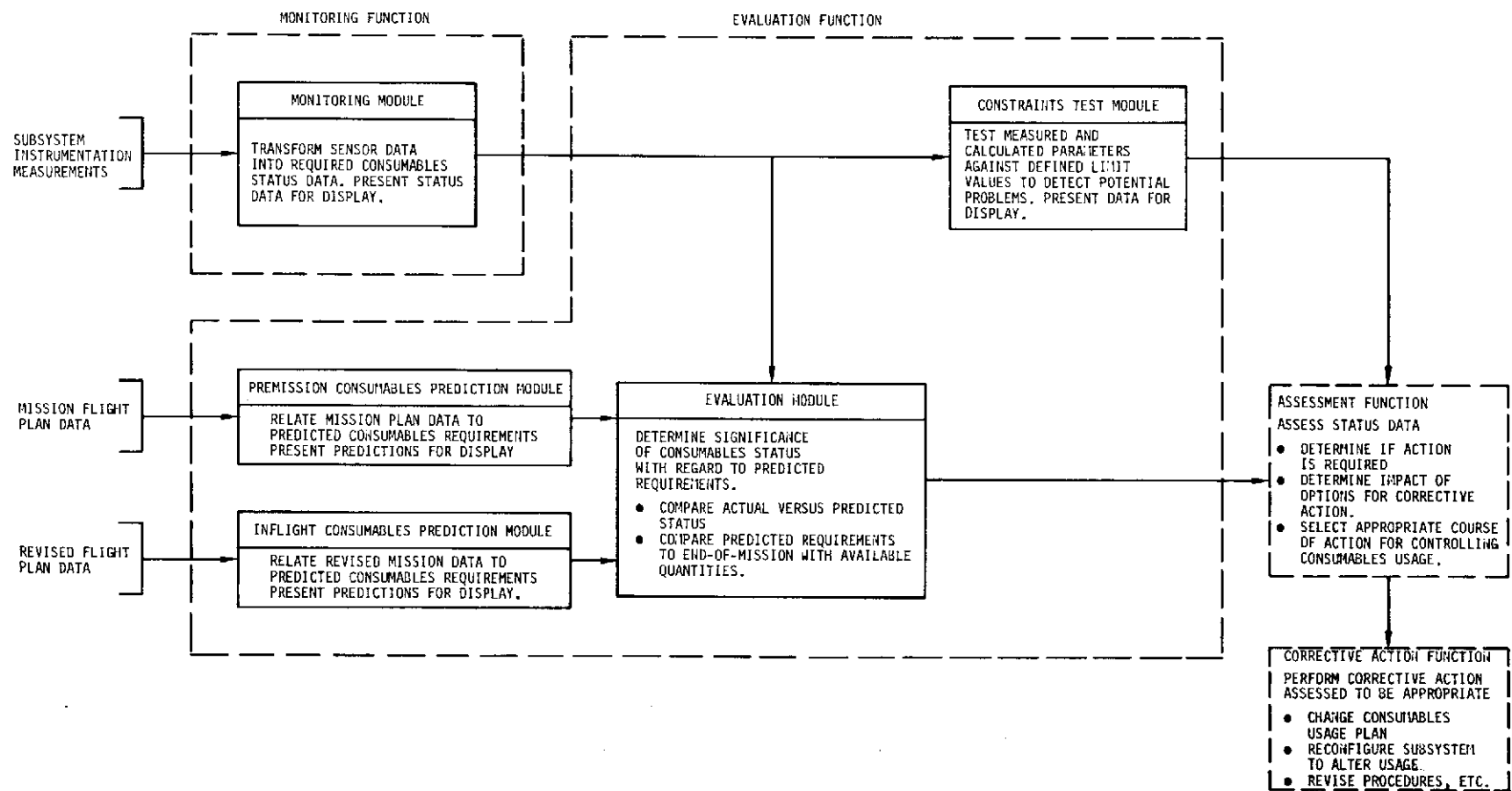


Figure 4-1. Relationship of Consumables Management Functions to the Defined Functional Modules

of increasing onboard capability which were evaluated for application to each vehicle consumable in order to develop a total shuttle vehicle consumables management system.

4.2.1 Minimum Onboard Capability Concept

The crew must be provided a level of capability for managing consumables usage when ground support is not available. This requires the crew to have the capability to determine the current consumables status and to make an evaluation of how the indicated usage relates to planned usage.

This capability is attained by providing onboard monitoring of consumables status and onboard storage of ground calculated premission consumable data. Comparison of actual usage data with the stored data will enable the crew to evaluate the consumables situation and to take corrective action.

As illustrated in Figure 4-2, the onboard monitoring capability is redundant to the ground monitoring. Under normal operation the primary responsibility for the monitoring, evaluation and assessment activities will be controlled by the ground support complex. The crew will implement corrective action procedures provided by ground support.

4.2.2 Intermediate Onboard Capability Concept

A second level of onboard capability is provided by the consumables management concept shown in Figure 4-3. In addition to onboard monitoring of consumables status data, the monitored data is tested for violations of limit values to alert the crew of potential problems. The constraints testing, which can be readily performed by the onboard software for most parameters, will not only serve to relieve the crew of the necessity for continual observation of monitored data but will also relieve the ground support complex of responsibility for continually observing telemetry data for out of tolerance conditions. However, under this concept, the primary responsibility for consumables status monitoring remains with the ground support personnel. This concept begins to divide the primary responsibility between the ground and onboard system by moving the prime function of constraints testing to the onboard system.

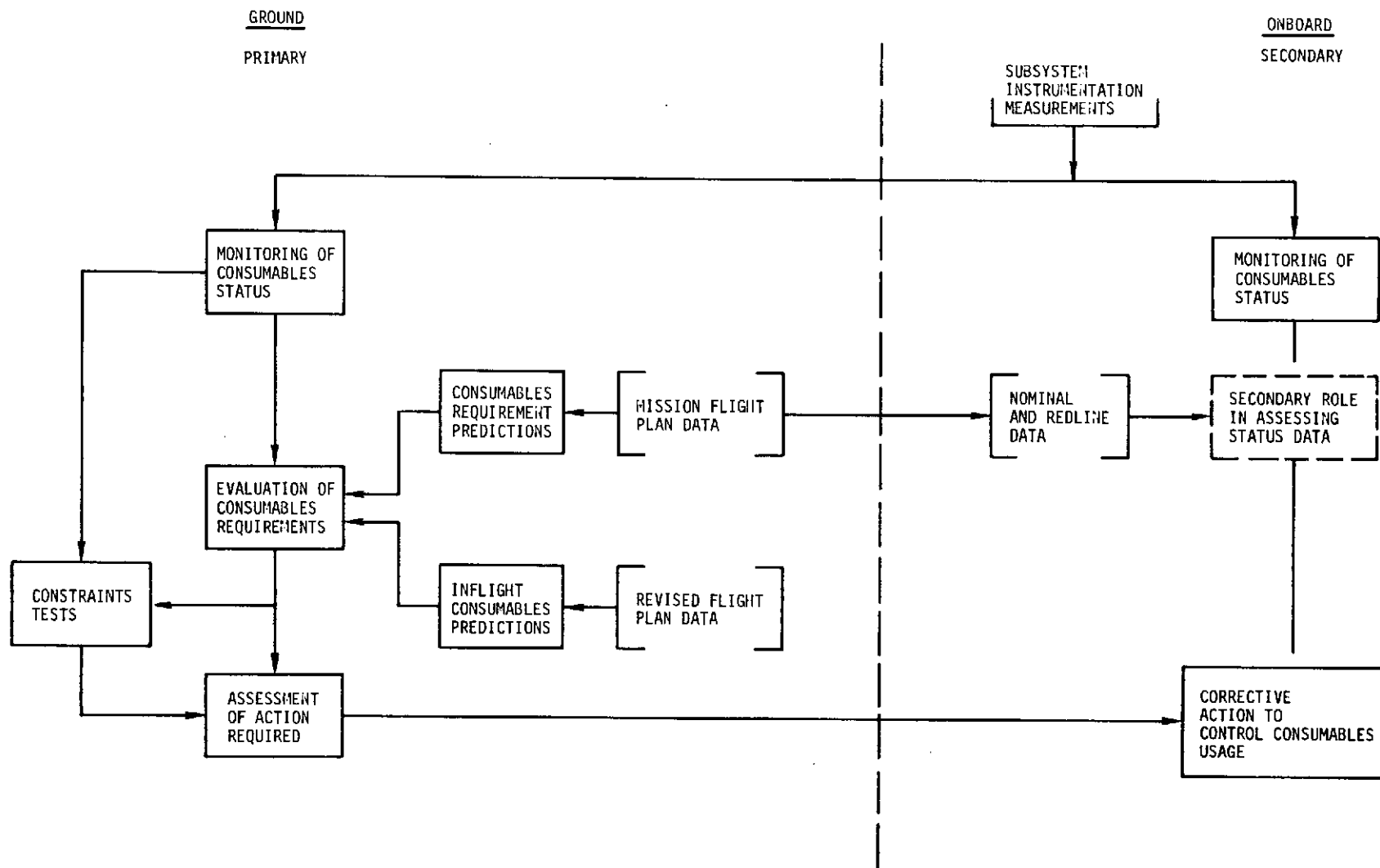


Figure 4-2 Minimum Onboard Capability Concept

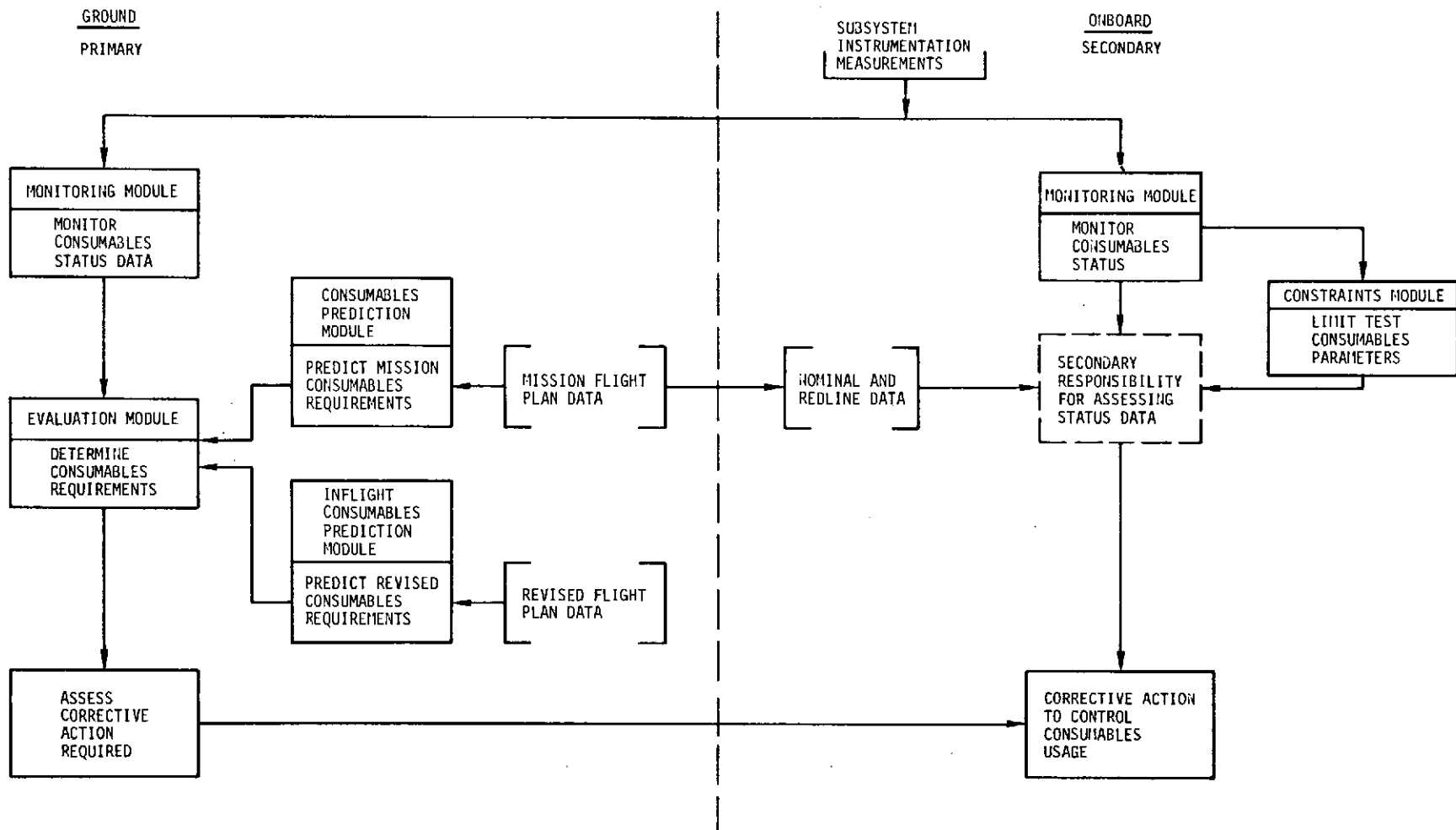


Figure 4-3 Intermediate Onboard Capability Concept

4.2.3 Advanced Onboard Capability Concept

Consumables management support of onboard mission revisions requires that onboard capability exists to predict consumables usage for the revised mission, to evaluate predicted requirements as compared to consumables available, and to assess the impact of the revised requirements on the remainder of the mission. Provisions for onboard replanning, as shown in Figure 4-4, requires a significant increase in the number of functions assigned to the onboard system, and it reduces the ground support complex role in meeting requirements for evaluating and revising consumables usage plans.

This concept can be implemented with various degree of sophistications ranging from a very simple onboard capability to accommodate minor mission revisions to a very comprehensive capability to support autonomous operation for both nominal and contingency missions. The exact functions of the ground support complex and the onboard capability should be defined as a total system.

4.2.4 Advanced Onboard Capability with Automatic Replanning Concept

Proposed mission revisions which impact consumables usage may frequently be evaluated by direct transfer of data within the avionics software to initiate the consumables management replanning sequence. Results of calculations which provide data such as revised engine burn schedules, mission duration, mission phase changes, etc., may be used to produce revised consumables requirements.

The consumables management system which provides automatic replanning capability is illustrated in Figure 4-5. It should be noted that no additional onboard functional modules are required for this system as compared to Figure 4-4; only the provision for supplying input revision data via a software interface has been added.

4.3 SHUTTLE CONSUMABLES MANAGEMENT CONCEPT

Subsystem designs and procedures by which subsystems are operated makes it necessary to evaluate each subsystem and its consumables on an individual basis in order to ascertain which of the general concepts most

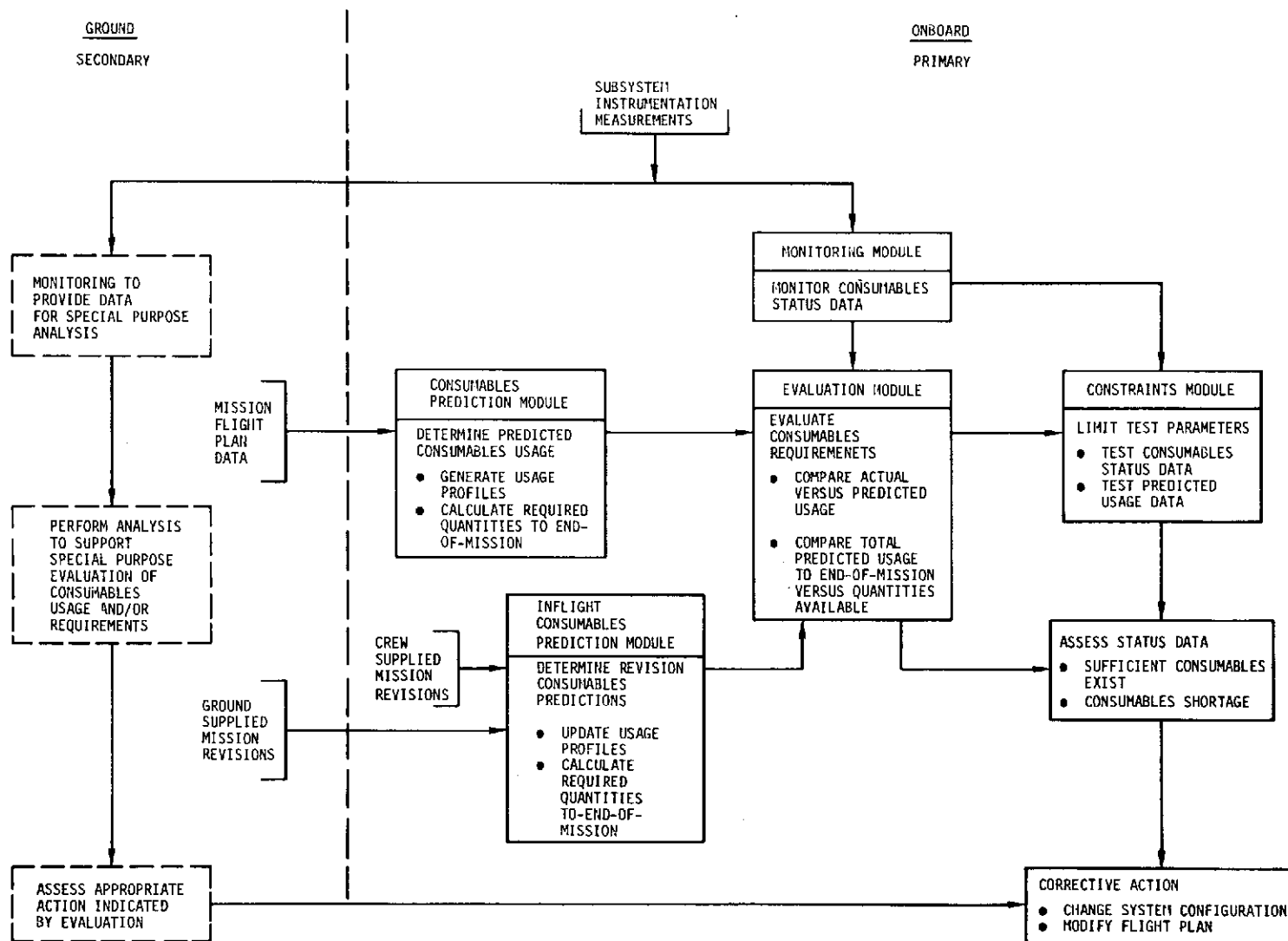


Figure 4-4 Advanced Onboard Capability Concept

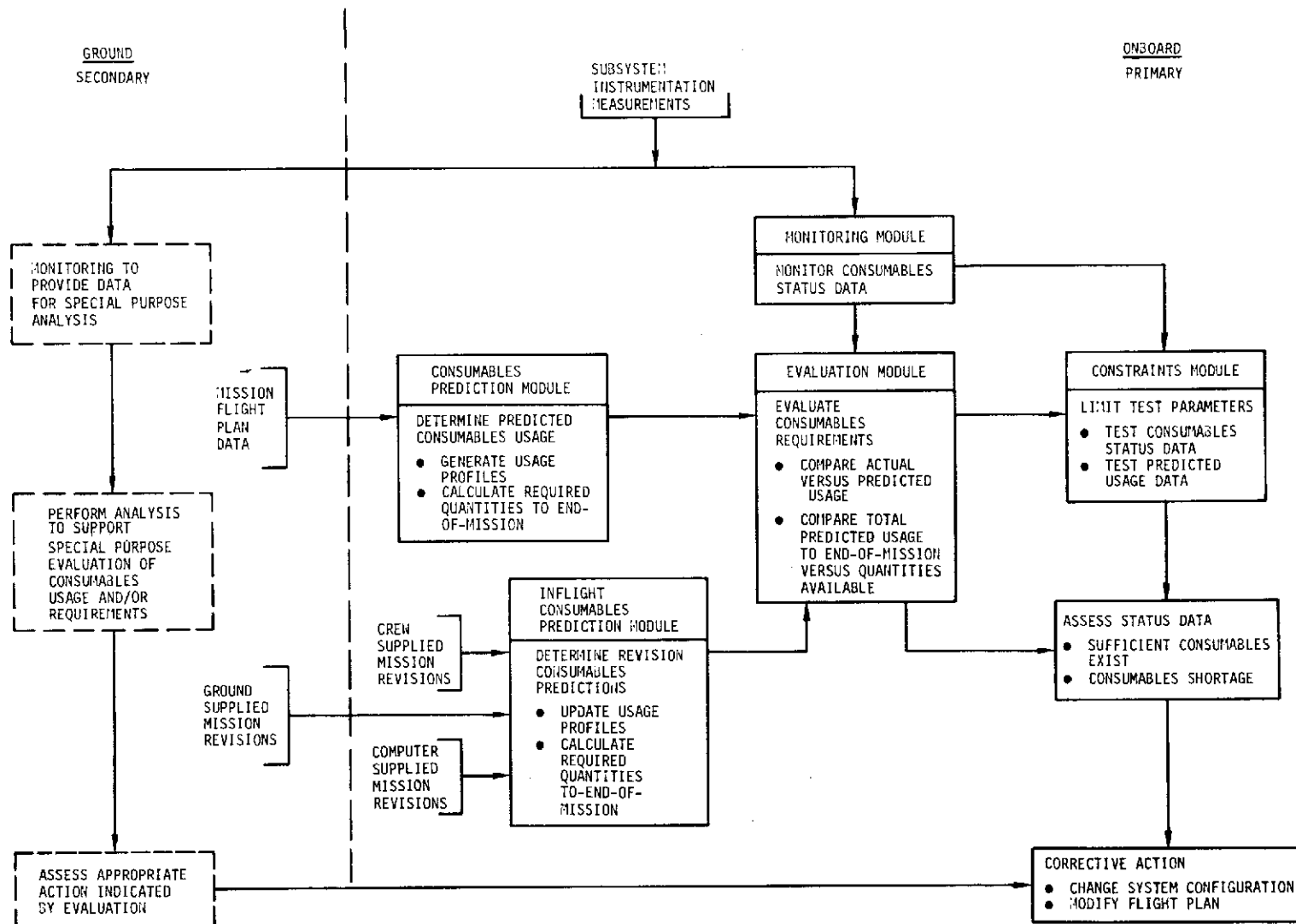


Figure 4-5 Advanced Onboard Capability Concept with Automatic Replanning

nearly meets the requirements for managing a particular consumable. The results of evaluating the requirements for management of each vehicle consumable and selection of a general concept which best meets those requirements are illustrated by the proposed shuttle consumables management concept.

Evaluation of the consumables management requirements for the operational Space Shuttle resulted in selection of varying degrees of onboard capability for managing the various consumables. Thus, the Shuttle consumables management system is not one of the general concepts but it is rather a composite of concepts resulting from selecting the capability necessary to effectively manage each consumable. This is shown in summary form in Table 4-1, where each consumable is listed along with an indication of the general onboard capability which most nearly describes its consumable management features. Table 4-2, provides a more detailed description of the techniques employed to manage the consumables.

The modular approach by which the Shuttle concept is presented makes it easy to implement a phased approach for developing the onboard consumables management system. A particular consumable may be managed initially with minimal onboard capability similar to the technique shown in Figure 4-2. Successive additions of onboard capability could eventually result in a technique as illustrated in Figure 4-5 which provides extensive assistance to the crew in performing their consumables management activities without reliance on continual ground support.

4.4 FUNCTIONAL AREAS DEFINED FOR CONSUMABLES MANAGEMENT SYSTEM

Detailed functional requirements were generated for the Shuttle consumables management system proposed in this report. The requirements specify the general functions to be accomplished by the total consumables management system as well as the functions required for management of the consumables of each vehicle subsystem. In addition, functional requirements are specified for the interfacing ground and onboard systems required to support operation of the consumables system.

The detailed functional requirements are contained in Section 6. of this volume.

Table 4-1 Summary of Shuttle Consumables Management Features

<u>Consumable</u>	<u>Onboard Monitoring</u>	<u>Onboard Constraints Tests</u>	<u>Onboard Replanning</u>	<u>Onboard Automatic Replanning</u>
ECLSS Ammonia	x	x	x	x
ECLSS Nitrogen	x	x	x	x
ECLSS Water	x	x	-	-
ECLSS Oxygen	x	x	x	x
ECLSS Lithium Hydroxide	x	x	x	x
FCCS Oxygen	x	x	x	x
FCCS Hydrogen	x	x	x	x
MPS/ET Propellant	x	x	-	-
OMS Propellant	x	x	x	x
RCS Propellant	x	x	x	x
APU Fuel	x	x	-	-
APU Cooling Water	x	x	-	-

Table 4-2 Summary of Shuttle Concept Features

	<u>Preflight Consumables Planning</u>	<u>Onboard Consumables Planning</u>	<u>Inflight Consumables Planning</u>	<u>Usage Prediction</u>	<u>Monitoring</u>	<u>Evaluation</u>	<u>Constraint Tests</u>
ECLSS Nitrogen and Ammonia	Ground function. Calculate total mission requirements and usage rate profile.	Onboard entry of ground supplied data.	Onboard manual or automatic function. Add or delete certain events or modify usage rates.	Onboard automatic function. Calculate requirements to end of mission based on events and usage rates.	Onboard automatic function. Monitor usage rate and quantity remaining.	Onboard automatic function. Calculate end-of-mission reserves, actual/predicted value comparison, and time to break redline.	Onboard automatic function. Test values for end-of-mission reserves, actual/predicted comparisons and time to break redlines against limit values.
ECLSS Water	Ground function. Calculate dump and sublimation times. Establish quantity limits.	Onboard entry of ground supplied data.	No function.	Onboard automatic function. Calculate tank time-to-empty and time-to-full based on current usage rates.	Onboard automatic function. Monitor quantity and quantity change rate for each tank.	Onboard automatic function. Calculate time-to-full and time-to-empty values based on existing quantities and usage rates.	Onboard automatic function. Test tank quantities against upper and lower limit values.
ECLSS Oxygen	Ground function. Calculate total mission requirement and usage rate profile.	Onboard entry of ground supplied data.	Onboard manual or automatic function. Modify ECLSS timeline or usage rate for remainder of mission.	Onboard automatic function. Calculate O ₂ requirements to end of mission.	Onboard automatic function. Monitor quantity in storage tanks and ECLSS oxygen flow rate.	Onboard automatic function. Calculate quantity required to complete mission.	Onboard automatic function. Test storage tank quantity and usage rate against limit values.
ECLSS Lithium Hydroxide	Ground function. Determine LiOH cannister change cycle.	Onboard entry of ground supplied data.	Onboard manual or automatic function. Modify mission time remaining or change-cycle values.	Onboard automatic function. Calculate cannisters required to end of mission based on remaining mission time and change cycle.	Onboard manual function. Determine LiOH cannisters remaining in response to crew input of cannisters used.	Onboard automatic function. Calculate end-of-mission reserves of LiOH cannisters, actual/predicted value comparison and time to break redline.	Onboard automatic function. Test end-of-mission reserves, change cycles, and time to break redline against limits.
FCCS Oxygen and Hydrogen	Ground function. Provide mission event timeline.	Onboard software. Process mission event timeline to provide electrical power event timeline and purge schedule.	Onboard manual or automatic function. Add, delete, or reschedule mission events which are processed to provide revised power event timeline and purge schedule.	Onboard automatic function. Calculate O ₂ and H ₂ usage versus MET based on fuel cell current, fuel cell purge requirements, and ECLSS usage rate.	Onboard automatic function. Quantity values are obtained from cryo quantity sensors. Flow rates are computed from rate of quantity change.	Onboard automatic function. Calculate end-of-mission reserves, actual/predicted value comparison, and tank balance.	Onboard automatic function. Test limits for end-of-mission reserves, actual/predicted values, tank balance, and usage rates.
MPS/ET Liquid Oxygen and Liquid Hydrogen	Ground function. Calculate loading requirements and ΔV -Remaining versus MET predictions.	Onboard entry of ground supplied data.	No function.	No function.	Ground/onboard function. Ground has primary role. Onboard software determine ΔV remaining and velocity residual.	Ground function.	Ground function. Onboard software indicates ΔV remaining and velocity residual limit violations for backup information.
OMS Monomethylhydrazine and Nitrogen Tetroxide	Ground function. Provide major event timeline.	Onboard software. Process timeline to provide burn schedule.	Onboard manual or automatic function. Add, delete, or reschedule OMS burns based on event timeline revisions.	Onboard automatic function. Calculate propellant usage requirements versus MET based on scheduled OMS burns.	Onboard automatic function. Software computes propellant quantities from engine on-time values.	Onboard automatic function. Calculate end-of-mission reserves and remaining ΔV capability.	Onboard automatic function. Test limit for ΔV end-of-mission reserve.
RCS Monomethylhydrazine and Nitrogen Tetroxide	Ground function. Provide major event timeline and attitude timeline.	Onboard software. Process major event and attitude timeline to provide RCS event schedule.	Onboard manual or automatic function. Add, delete, or reschedule RCS events based on event timeline revisions.	Onboard automatic function. Calculate propellant usage requirements versus MET based on scheduled RCS events.	Onboard automatic function. Monitor quantity in each tank by software calculation from weighted PVT measurements.	Onboard automatic function. Calculate end-of-mission reserves, actual-predicted value comparison, tank balance, and propellant outage.	Onboard automatic function. Test limits for end-of-mission reserves, actual/predicted values, and tank balance.
APU Hydrazine and Cooling Water	Ground function. Calculate mission requirements and usage profiles.	Onboard entry of ground supplied data.	Ground or onboard manual function. Crew will follow standard procedures for given quantity conditions.	No function.	Onboard automatic function. Monitor quantity values for each tank and software computes usage rates from rate of quantity change.	Onboard manual function. Crew compares quantity remaining values with nominal usage profiles and redline values.	Onboard automatic function. Test limits for usage rates and time to break redlines.

5. TECHNICAL DISCUSSION

This section presents the supporting data for the consumable management concept development and for the generation of the functional requirements for onboard management of Shuttle consumables. The section is organized in the general sequence in which the study was performed in order to show the study progression and to provide a logical organization of interim study results.

5.1 CONSUMABLES MANAGEMENT REVIEW

Consumable management reviews included both aircraft and manned spacecraft operations and covered the preflight, inflight, and postflight activities. The purposes of the reviews were to determine the general philosophy, operational procedures, and management tools employed by various groups associated with the different facets of the consumables management process.

5.1.1 Apollo Consumables Management Review

This review included examination of the preflight, inflight, and postflight activities associated with each Apollo consumable subsystem. Particular attention was given to the inflight ground and onboard operational procedures in order to better understand the philosophy used on the Apollo program for consumables management. The Apollo vehicle systems considered in this report consisted of the following

- Command Service Module (CSM) Vehicle Systems
 - Service Propulsion System (SPS)
 - Reaction Control System (RCS)
 - Environmental Control System (ECS)
 - Electrical Power System (EPS)
- Lunar Module (LM) Vehicle Systems
 - Descent Propulsion System (DPS)
 - Ascent Propulsion System (APS)
 - Reaction Control System (RCS)
 - Environmental Control System (ECS)
 - Electrical Power System (EPS)
- SIVB Vehicle System
 - Main Propulsion

Apollo Consumables Management Review Summary. The Apollo review of consumables management revealed that there were a number of philosophies employed in subsystem consumable management. However, these philosophies were not always different and distinct. In many cases, the philosophies were related because of common goals between the systems.

These goals required management of the consumables to ensure crew safety and meeting mission objectives. To meet these goals, different emphasis of the consumable management phases were placed on each subsystem. Some subsystems only required monitoring, while others required monitoring and analysis and still others required monitoring, analysis, recognition and action. Examples of the latter includes SM RCS and LM EPS where the systems were closely regulated. Trend analysis was used to assess deviations from the preflight predictions and there was an assessment phase to determine if continued usage at the observed rate would impair downstream activities. Finally, there was the modification of scheduled events to correct the situation. Not all of the consumables subsystems required management to the same degree as the SM RCS and LM EPS, but some form of management was used on each system.

The vast majority of the Apollo consumable management effort was performed preflight during the mission planning phase. Inflight consumable management consisted of monitoring, assessing deviations from preflight predictions and taking the necessary corrective action. For nominal missions, only the monitoring was required. However, usually all phases of consumable management was required on a typical Apollo flight. Tables 5-1 and 5-2 summarize the Apollo consumable management philosophy for the different subsystems.

The following statements highlight the Apollo consumable management philosophy:

- The consumables management philosophy was a function of the individual consumable subsystem to be managed and the types of mission to be performed.
- Consumable management decisions were the result of trend analysis and prediction techniques.

Table 5-1 Control & Propulsion Subsystems Summary

SYSTEM	CONSUMABLE MANAGEMENT PHILOSOPHY
CM RCS	Management by excess resulted from contingency deorbit requirements which provided approximately four times the nominal requirements
SM RCS	Long duration mission, high mission priorities, usage closely monitored, "pinklines" used to anticipate possible impact and correct very early in mission; redline management
LM RCS	Short duration usage period, usage determined by phases, subsystem performance primary; redline management
SM SPS	Monitor ΔV remaining - closely calculate actual engine performance used to update model with flight data - consumable management secondary, PU value to optimize outage
LM APS	Preflight analysis, stopwatch monitoring
LM DPS	Sophisticated depletion monitoring and predicting scheme, preflight analysis
SIC, SII	Burn to depletion
SIVB	Monitor performance, reconstruction program to predict restart performance

Table 5-2. Electrical & Environmental Subsystems Summary

SYSTEM	CONSUMABLE MANAGEMENT PHILOSOPHY
<div>CSM EPS</div> <div>CSM ECS</div> <div>CRYO</div>	<p>Cryo usage rate monitoring for fuel cell performance</p> <p>Usage prediction and tank management, cryo tanks sized for critical point failure (critical point similar to point of no return)</p>
<div>LM EPS</div> <div>DSC</div> <div>ASC</div>	<p>Limited amount of energy, balance A-H usage, manage to adhere to preflight estimates, redline management</p> <p>Two times margin value</p>
LM ECS	Monitor and compare with preflight
CSM LiOH	Preflight scheduling
LM LiOH	Limited number of cartridges requires close monitoring and attempts to optimize cartridge use
CSM WATER	Scheduling dump on non-interference basis
LM DSC WATER	Close monitoring/predicting required because of off-load to improve hover margins; and increased lunar stay time

- Mission rules and crew safety sometimes dictates consumables management schemes.
- In many cases, consumable usage was directly related to system performance and as such consumables management was incorporated into system monitoring schemes.
- Redline management was used on several of the consumables subsystems.
- The ground had primary responsibility for consumable management; however, onboard backup was available.

Apollo Control and Propulsion Systems. The applicable consumable subsystems for the CSM were the SPS and RCS, and for the LM, the DPS, APS, and RCS. Basically, the preflight preparation for each subsystem was the same. The subsystem predicted usage was determined using a "nominal" mission timeline. The preliminary analysis not only included determination of nominal expected usage but also included propellant loading analyses, mixture ratio outage, and determination of statistical parameters affecting total propellant usable.

The preflight consumable effort was primarily performed by the Mission Planning and Analysis Division (MPAD), of JSC. Using computer programs designed for consumable analysis, the preflight predictions were generated using the nominal mission timeline. Following the completion of the preflight predictions, the mission redlines (prepared by the applicable mission flight controller) were superimposed over the preflight predictions to provide guidelines for the real-time mission activities.

Mission redlines define the minimal acceptable consumable remaining at any point in the mission required to accomplish a specific goal. For the CSM, one goal was to ensure sufficient SM RCS to perform a LM rescue. Following LM docking, the redline goal became one of ensuring sufficient SM RCS for a safe return to earth. Generally, redline usage was determined by using a vehicle in the powered down mode and eliminating all RCS activities except those which were mission essential.

Therefore, redline consumable management dictates that when the actual consumable usage exceeds the redline values, the nominal mission activities will be stopped and the vehicle will assume a minimum consumable usage

mode. Nominal mission activities may be resumed when the actual consumable quantities remaining become greater than the redline value.

The real-time mission support was performed by the Flight Control Division (FCD) of JSC. The Mission Control Center displays for both the CSM and LM were similar. They provided pertinent consumable information in the form of quantity remaining and, in the case of propulsion, delta-V remaining. Also, subsystem parameters for system performance and evaluation were displayed.

Each of the CSM and LM control and propulsion systems had three flight controllers directly concerned with the monitoring and assessment of subsystem performance, and consumable analysis and management. Trend analysis was the primary technique used in determining real-time consumable updates.

In addition to the displays and preflight budget estimates, the flight controllers had a variety of computer programs available for mission planning to assist in the development and assessment of alternate mission plans. A list of these programs include

- CSM
 - Olivetti Desk Computer Programs:
 - SPS delta-V capability
 - SPS burn time for given delta-V
 - SPS delta-V for given burn time
 - SPS propellant required for given delta-V
 - SPS burn data for channel 65 TV display
 - SPS propellant weights to percent
 - SPS propellant percents to weight
 - Determine S/C weight when exact delta-V obtained and propellant used is given
 - Split propellant into amounts of fuel and oxidizer at given ratio and indicate excess of fuel or oxidizer
 - RCS delta-V capability
 - RCS WPU to percent remaining
 - Predicted rate for single RCS thruster firing
 - Usage or leak rate determination
 - Off-line Programs:
 - CSM (SM RCS) consumables computer program

- LM
 - Olivetti Desk Computer Programs:
 - Weight update, propellant remaining and delta-V determination
 - APS burn time remaining
 - Burn time to delta-V determination
 - CG and DPS gimbal angle determination
 - Real-time RCS propellant profile determination*
 - RCS capability to perform LM tweak
 - Optimum LM ASC stage/CSM docking angle determination
- Off-Line Programs:
- LM RCS consumables computer program

In addition to the computer programs, trend plotting was also used in the determining and assessing of consumables deviations. Typical trend plotting for the control and propulsion systems included

- RCS propellant
- RCS quad temp
- SHe pressure
- APS propellant usage
- DPS propellant usage

The CSM activities occurred over approximately twelve days and involved diverse activities which not only included transporting the LM to the moon, but included scientific experiments, lunar photography, and many other activities. The LM-active propulsion portion was less than five hours, consequently different priorities were established for each vehicle. There was a reordering of priorities as the Apollo program matured. This re-ordering caused a change in the consumables management philosophy with regard to the SM RCS. The initial Apollo program objectives placed a majority of the emphasis on the successful lunar landing and considerably less emphasis on the CSM activities. This priority resulted in a consumable management philosophy whereby the flight controllers and flight planners were only concerned that the actual usage did not cross the mission redlines. The SM RCS usage was monitored, but very little action was required if the actual usage exceeded the nominal predicted.

*Hewlett Packard Calculator

Following the successful Apollo 11, 12 and 14 lunar landing missions increased emphasis was placed on the CSM activities with regard to its scientific data and photographic acquisition capability. Consequently, there was a change in the amount of consumable management required for the SM RCS.

The J-series Apollo missions, Apollo 15, 16 and 17, involved a coordinated effort between MPAD, FCD, and CPD (Crew Procedures Division) in the managing of the SM RCS. The SM RCS usage was closely monitored and continually compared to the preflight prediction. For the J-series Apollo missions, it was not always acceptable if the usage dropped below the predicted value but still remained above the redline. A new set of guidelines called "pinklines" were established by the flight planners to aid in assessing the impact on experiments and other CSM activities downstream in the mission if the existing usage rate were to be continued. The redline philosophy dictates that once the remaining consumable hits the redline all activities stop and the vehicle performs wide deadband attitude hold. The pinklines were added to anticipate a downstream crossing of the redlines and to take the necessary corrective action so that the redlines would not be crossed and that important CSM activities might still be performed.

The CM RCS was unique in the Apollo consumable subsystems. The CM RCS system was sized for contingency deorbit which might have resulted from a failure in the primary system. This deorbit consideration resulted in a system sizing of approximately four times the nominal entry requirements. Consequently no management was required for the nominal entry. This system serves as an example of the "management by excess" technique. "Management by excess" is the technique whereby the consumable system is sized several times maximum anticipated usage. Because of this large reserve, no management is then required. This technique is only applicable when there are no weight or volume constraints associated with the system.

The LM DPS and APS served to demonstrate how mission requirements influence the consumable management scheme. The LM DPS consumable subsystem employed a sophisticated depletion monitoring and predicting scheme, with both onboard and ground capability used during the powered descent phase.

The LM APS consumable subsystem did not have onboard monitoring capability and the ground monitoring scheme was basic. A stopwatch was used during the ascent burn to determine total engine on time. Knowing the total engine on time and the propellant flow rate, the total APS propellant used and the amount remaining was then calculated. These data were then used in the APS TPI go/no-go decision.

The reason for the difference in emphasis placed on the consumable management scheme was the abort criteria used during the descent and ascent phases. During descent there were numerous abort opportunities based on consumable status, system performance, and trajectory parameters. Consequently, detailed monitoring and predicting capability was necessary to establish if, and when, an abort from descent was required. There was no abort possible during ascent. If necessary, the engine was to be burned to depletion to achieve a safe insertion orbit. Therefore, the monitoring and predicting requirements were minimal and stopwatch monitoring was sufficient.

The postflight activities were directed to two areas: evaluation of mission anomalies, and evaluation of models and techniques used in determination of preflight consumable budgets.

MPAD's postflight activities were primarily aimed at updating propellant budgeting models and budgeting techniques by equating real-time flight procedures with propellant usage. Postflight analysis performed in the Engineering and Development Directorate (E&DD) concentrated on the software and hardware performance during a mission. Because of the interrelationship of system performance and consumable usage, often the efforts of E&DD were combined with MPAD's analyses to improve the preflight estimates.

SIVB Propulsion Systems. No propellant consumption calculations were made in real-time for the Saturn stages, although the measurements of propellant mass, flow rate and engine pressures were monitored. However, after the first burn of the SIVB stage a postburn reconstruction was performed utilizing a detailed propulsion system simulation (computer program) and flight measurements. This information was used to update and revise

the prediction model, and then to repredict the final SIVB burn. This allowed a more accurate determination of SIVB propellant required and available for the final burn.

Both the SIVB and SPS contained a propellant utilization (PU) value to allow balancing between the oxidizer and fuel. When the SPS propellant mass unbalance exceeded a predetermined amount, the crew would adjust the engine mixture ratio with the PU value to drive the unbalance towards zero. This procedure maximized the use of available propellants. Positioning of the SIVB PU valve was performed by the launch guidance computer. Initially the SIVB PU valve was positioned to provide high thrust. At a predetermined time during the burn, the valve position was switched to minimize propellant outage. For Apollo mission which used the SIB as the main booster, the SIVB PU valve positioning was closed loop with active computer control to maximize propellants. For the remainder of the Apollo missions, the valve was present, based on preflight predictions, and was moved only once to reduce propellant outage.

Electrical and Environmental Systems. The environmental control and life support system (ECLSS) and the electrical power system (EPS) consumables include water (H_2O), cryogenics (H_2 and O_2), gaseous O_2 , LiOH and battery amperes hours (A-H).

The main difference between the CSM and the LM EPS and ECS systems resulted from the electrical power sources. The CSM used a fuel cell system with battery backup while the LM used only a battery source system. The system configuration difference resulted in a slightly different emphasis being placed on the consumables. For example, water on the CSM was an excess consumable and had to be periodically dumped, while on the LM it was a limited quantity and as a result had to be carefully managed.

As with the propulsion systems, the preflight consumable analysis effort was primarily performed by using computer programs specifically designed for consumable analysis. Unlike the propulsion systems, the preflight consumable analyses were performed to not only determine consumable usage but to analyze possible constraint violations (e.g., low voltage on

the EPS analysis). The CSM EPS and ECS analyses were performed in two steps. First the Spacecraft Electrical Energy Network Analysis computer program was used to demonstrate that the EPS system can satisfactorily handle all EPS electrical loads without undervoltages, out of limit current spikes, etc. Then the output of this program, total spacecraft current profile, fuel cell output, electrical heat loads, temperatures, and ECS data was input into a cryogenic usage program to determine the O_2 and H_2 requirements.

The real-time EPS and ECS mission support was performed by the Flight Control Division (FCD) of JSC. The division of responsibility placed the direct consumable management of cryos with ECS flight controllers. The EPS flight controllers had primary responsibility for the fuel cell system performance. The CSM EPS/ECS provides a good example of how difficult it often is to separate the consumable management role from subsystem performance monitoring.

Normally, one aspect of consumable management involves the monitoring of consumable flow rates; however, since the cryo (O_2 , H_2) flow rates for fuel cells were one of the main monitoring points to determine fuel cell performance, the EPS flight controllers had the responsibility for monitoring and assessing fuel cell cryo flow rates. All other aspects of the cryo management were performed by ECS personnel.

Two types of consumable management were performed in the CSM cryo system. First, there was the analysis, evaluation, and projection of the total cryos available at any time in the mission, and second there was the management of the cryo storage system tanks to ensure that the tanks did not all pass through the minimum dq/dm^* point at the same time and that the crew could safely return with a single tank failure.

The LM electrical power sources were very limited as compared to the CSM. When the electrical energy of the batteries were depleted there were no provisions for recharging. Therefore, strict adherence to the preflight predictions was required. All deviations from the nominal were assessed

* dq/dm is the specific heat input in BTU/lb required to withdraw one pound of fluid from the system at a specified fluid pressure

immediately and in some cases recommendations for reducing loads were made to make-up the amp-hour usage above the predicted usage.

The aim of the LM battery management was two fold; first, to balance the A-H usage per battery, and second, to maintain total usage as close as possible to preflight predictions. Descent battery management was performed in real time on the lunar surface using the nominal four descent batteries and the single lunar surface battery. The objective of the management was to keep all five batteries within 100 A-H of each other. This philosophy was to prevent a single (or possible double) battery failure from jeopardizing the mission.

Because of the large margins (52 percent) remaining at docking, there was very little real time ascent battery management.

In addition to electrical energy, the LM consumables included water and oxygen. The water and oxygen management was performed by comparing actual usage with preflight predictions and assessing deviations. Water management was required on the LM because, to increase the DPS landing propellant reserves, DPS water was off-loaded. Consequently, the water reserves were lowered which resulted in water usage being closely monitored and managed during the mission.

The Mission Control Center displays for the two vehicles were essentially the same. Pertinent system performance parameters were displayed along with cryos remaining. The battery amp-hours remaining were calculated and plotted on a curve where the preflight prediction had been plotted.

In addition to the displays and preflight estimates available, the flight controllers used several desk computer programs to assist in the determination and assessment of consumables. Typical programs included

- LM EPS ampere hour (AH) calculations
- Contingency translunar coast LM battery management
- H_2O/O_2 rate calculations
- O_2 quantity calculations

Several off-line programs were used in the event of major changes to the timeline which required the development of a new nominal usage profile to correspond to the revised mission. Typical offline programs included

- Apollo LM integrated ECS/Thermal analysis program
- LM atmospheric control analysis program
- LM descent O₂ analysis program
- Apollo CSM integrated ECS/thermal analysis program
- CSM radiator analysis program

The postflight effort in the ECS and EPS areas were performed to ascertain the differences between preflight and actual observed usages. Very little detailed analyses were performed unless there was a serious discrepancy between the predicted and actual. Specific areas of postflight analyses included CSM cryogenics (O₂, H₂), LM descent water and oxygen, and LM battery ampere-hours.

5.1.2 Aircraft Consumables Management Review

A review of the method by which the modern airlines manage consumables was performed. This review can be divided into two distinct phases. One, the normal aircraft consumables management and two, the more advanced performance monitoring systems such as the Airborne Integrated Data System (AIDS), the Malfunction Analysis, Detection and Recording (MADAR) System, and the Energy Management Analog Computer (EMAC) System.

Aircraft Consumables Management Review Summary. The major effort of airline consumables management is in the fuel subsystem. Currently, the majority of the commercial carriers calculate their fuel requirements using specification engine performance data. The calculated requirements are added to the Federal Aviation Requirements (FAR) reserve requirements to establish the fuel load quantities. The consumables management activities for all consumables are summarized in Table 5-3.

The airline crews perform manual recording of engine data during flight. These data are either manually or automatically analyzed to determine engine performance degradation by use of trend analysis. This method

Table 5-3. Commercial Carriers Consumables Management Summary

CONSUMABLES	GROUND PERSONNEL			FLIGHT PERSONNEL	
	PREFLIGHT	FLIGHT	POSTFLIGHT	PREFLIGHT	FLIGHT
Fuel	Calculate & Load	Status	Analysis	Verify Fuel Calculation	Monitor & Record
Oxygen	Calculate & Load	No Action	No Action	Monitor	Monitor
Oil	Check & Fill	No Action	Analysis	Monitor	Monitor & Record
H ₂ O	Check & Fill	No Action	No Action	No Action	No Action
Hydraulic	Check & Fill	No Action	No Action	Monitor	Monitor

of engine performance evaluation has proven to be invaluable in assisting in the scheduling of maintenance and inspection.

The investigation into the more advanced and automatic monitoring systems depict a slow but inevitable move by the modern airlines to incorporate automatic systems. The AIDS offer a method to reduce the flight crew work load by automatically monitoring and recording important parameters. MADAR allows for man/machine interface in tracing down a malfunctioned Line Replaceable Unit (LRU), while at the same time recording data on magnetic tapes. The recorded data is stored into the Ground Processing System of MADAR and is processed to allow for trend analysis, work order initiation, and general airplane information compilation. The EMAC System provides the flight crew with a tool for more rapidly evaluating plan changes or alternate flight modes.

The following statements summarize aircraft consumables management and subsystems monitoring approach:

- Consumables management techniques are developed on an individual subsystem basis with the fuel system receiving the most attention.
- Fuel reserves provide for contingency operations.
- Subsystem flight recorded data are used for inflight failure detection and isolation and for ground analysis to determine maintenance requirements.

Airline Consumables Management. The airlines consumables management is primarily accomplished for the following subsystems: fuel, hydraulic, oil, water, and emergency oxygen. Information from several major airlines concerning consumables management for these subsystems has been grouped and summarized.

Fuel Subsystem - The fuel requirements for a particular flight are calculated by using the aircraft engine manufacturer's performance curves. These data are used either manually or automatically to determine the fuel requirements, taking into account the expected weather conditions and the

flight plan. In some cases, the fuel calculations are accomplished on a per phase basis. Typical phases might be taxi to take-off, roll and take-off, ascent, cruise, descent, instrument approach, one wave off, alternate airport, landing, and taxi to gate. Factors such as weather, flight altitude, and landing sites are considered when determining the amount of fuel required for each of the phases.

The fuel required for a particular flight is calculated either manually or by the use of computer programs. In either case, the calculation is based upon the aircraft manufacturer's performance data and specifications. The Federal Aviation Requirements (FAR) state that the following should be considered in computing fuel requirements

- Wind and other weather conditions forecast
- Anticipated traffic delays
- One instrument approach and possible missed approach at destination
- Any other conditions that may delay landing of the aircraft

For the purpose of computing fuel requirements, required fuel is in addition to unusable fuel.

Fuel reserve requirements are set by FAR. The requirements differ with regards to whether the plan is nonturbine, turbo-propeller, or turbine engine powered. There are specific differences for the varying types, but the general fuel requirements for all flight operations of domestic air carriers are as follows:

- To fly to the airport to which it is dispatched
- Thereafter, to fly to and land at the most distant alternate airport (where required) for the airport to which dispatched
- Thereafter, to fly for 45 minutes at normal cruising fuel consumption (varies slightly in overseas flights)

Inflight monitoring of fuel usage is performed by the crew. The usage is compared to the nominal to verify adequate fuel margins during the flight. In conjunction with the fuel data, engine data (inlet temperature, spool speed, exhaust pressure ratio, etc.) are recorded during flight. This recorded data is not used by the crew, but upon landing is used by ground personnel to evaluate individual engine performance. The data is used for trend monitoring and is very useful in predicting engine maintenance requirements.

Oil Subsystem - The oil system is checked on a daily basis. It is monitored by the flight crew by onboard gauges and by maintenance personnel by dip stick. The oil quantity is verified to be filled to at least the minimum allowable. The oil consumption rate for each engine is used in conjunction with spectrographic analysis and the quantities of oil added to allow trend analysis calculation by ground support personnel.

Water Subsystem - The water requirements are not calculated on each flight. Instead, the ground maintenance personnel check and verify the system to be full. The airlines contacted in this review did not indicate any active water requirements calculations, therefore, it is assumed that the ground maintenance personnel apply their experience in estimating whether there is sufficient water onboard for a particular flight.

Oxygen Subsystem - The oxygen subsystem is serviced to comply with the Federal Aviation Requirements applicable to the particular type of craft. After the system has been serviced it is monitored via pressure readouts by the flight crew. There is no "consumables management" of the subsystem other than the initial loading and the periodic monitoring to insure compliance with the FAR.

Hydraulic Subsystem - This subsystem is serviced and monitored to verify correct pressure and temperature during flight. The monitoring is accomplished by the flight crew. The hydraulic fluid represents a "non-consumable" which requires monitoring to insure subsystem operation readiness.

Advanced Monitoring Systems. The three advanced monitoring systems discussed are the Airborne Integrated Data Systems; the Malfunction Detection, Analysis and Recording System; and the Energy Management Analog Computer System.

Airborne Integrated Data Systems (AIDS) - Airborne Integrated Data Systems are essentially data acquisition systems. Depending upon the degree of sophistication of an AIDS, it may only acquire data and store it on a magnetic tape, or it may acquire the data, check for out-of-tolerance conditions, activate caution and warning systems, perform data compression, perform malfunction detection analysis, display data, print hard copy of data, etc. AIDS is a tool which eliminates the flight crew from manually recording data and in addition gives a larger monitoring capability.

Typical AIDS operational functions are to obtain the data from a sensor at a predetermined rate and compare this data to pre-set limits which might be fixed, floating, or adaptive depending upon the item being checked and the flight mode. If the value is within limits it is recorded, but if it is out of tolerance, a caution and warning panel indicator might be activated. The sampling rate is automatically increased, and possibly a malfunction detection program might be keyed into action. It is obvious from this discussion that AIDS will accomplish several functions if the user has the finances to purchase the additional sophistication. The technology required for AIDS is available and is beginning to be used operationally by the major carriers with their large jetliners.

Malfunction Detection, Analysis and Recording System (MADAR) - The Malfunction Detection, Analysis and Recording System which is used on the C-5A military transport is similar to a sophisticated AIDS. This system receives approximately 1024 signals from various Line Replaceable Units (LRU) throughout the plane. With the use of various software programs stored in the 8,000 word digital onboard computer, the data is checked for out of tolerance conditions. Data compression techniques are applied, and then the pertinent data is recorded on tapes. MADAR has self-test capability to verify proper operation.

The MADAR system is capable of being operated in the automatic mode or manual mode. When in the manual mode, the operator can troubleshoot problems by calling up an applicable display and proceeding as directed by the computer messages displayed on the Data Retrieval Display Unit. With this aid, the operator is led through the particular subsystem in logical predetermined steps until the defective LRU is identified. In the automatic mode, the defective LRU's are identified automatically (within the limitations of the computer software).

The data that is recorded on the magnetic tapes is stored in the Ground Processing System (GPS). This system has several utility programs which allow calling up data files on a particular aircraft, a particular air base, the whole fleet, etc. The GPS has the capability to plot parameters for assisting in trend analysis monitoring.

The GPS of MADAR provides an example of massive data processing and storage. The MADAR system is an example of extensive use of computers and software, both onboard and ground, for subsystems monitoring and analyses.

Energy Management Analog Computer (EMAC) - The Energy Management Analog Computer is a system for management of the fuel onboard the C-5A. Using information such as average wind velocity and direction, temperature, and fuel quantity, the EMAC system determines the fuel required to fly the desired Mach number, optimum altitude, constant altitude, endurance altitude, etc. This system is a tool used by the flight crew to evaluate various options available in the management of the fuel system. The calculations performed by EMAC are based on nominal engine performance data, but at the operators decision the data may be biased to reflect a particular deviation from average fleet behavior.

The EMAC system is an LRU of MADAR and is an example of a semi-automatic consumables management tool.

5.2 CONSUMABLES MANAGEMENT STUDY GUIDELINES

Early in the study period, a research activity was conducted to define a set of guidelines to establish a base for the consumable management concept development. The guidelines were developed from inputs supplied

from the study contract statement of work, Shuttle program requirements, the Shuttle RFP, technical reports and papers on related subjects, the Rockwell International Shuttle proposal, and numerous conversations with personnel involved with similar activities for both spacecraft and aircraft programs.

From this research activity essentially two sets of guidelines were generated. The first set is relatively specific and was based mainly on the Shuttle RFP and the Rockwell International Shuttle proposal. The second set was more general in nature and was intended to encompass advanced spacecraft operations as well as the Shuttle vehicle. The following subsections present the results of the consumable management study guideline development research effort.

5.2.1 Shuttle Specific Consumable Management Guidelines

The following guidelines were developed from the Shuttle RFP and the Rockwell International Shuttle Proposal:

- a) RFP Requirement - Shuttle goal is to substantially reduce the cost of space operations.
Consumable Management Concept Guideline - Should show operational cost advantage by reducing premission planning, taking advantage of existing hardware/software to perform CM functions, and reducing costs of real-time ground support.
- b) RFP Requirement - Shuttle goal is to provide capability to support a wide range of scientific, defense, and commercial uses.
Consumable Management Concept Guideline - Should show increased mission capability and/or flexibility to support a variety of missions by efficient use of consumables, and provide onboard replanning capability.
- c) RFP Requirement - Flight hardware turnaround time from landing/return to launch facility readiness shall be less than 160 working hours covering a span of 14 calendar days for any class mission.
Consumable Management Concept Guideline - Any requirement for analysis of subsystem performance data and updating of CMS predictors must be capable of being performed within 14-day turnaround time.

- d) RFP Requirement - Capability shall be provided to launch from standby status within two hours, and hold in standby for twenty-four hours. (Standby status is defined as ready for launch except for main propellant fill, crew ingress, and final systems verification.)

Consumable Management Concept Guideline - Final CMS data required must be capable of entry into the CMS during standby period. (propellant loading and cryo loading)

- e) RFP Requirement - Redundancy requirements for subsystems shall not be less than fail-safe.

Consumable Management Concept Guideline - Back up consumables management capability must be provided to perform CMS functions.

- f) RFP Requirement - Space rescue role requires capability to launch within 24 hours after notification, assuming vehicle is mated and ready for transfer to the pad.

Consumable Management Concept Guideline - Must be capable of preparing and entering all necessary CMS data within 24 hours.

- g) RFP Requirement - Capability shall be provided to extend the orbital stay time up to 30 days. (Nominal accommodations are for 7 day mission for a 4 man crew.)

Consumable Management Concept Guideline - CMS must be capable of tracking usage and performing predictions for 30-day mission. (May require data compression for storage and display, and require different predictive capability for near-term and long-term consumable usage trends.)

- h) RFP Requirement - Orbiter designed for orbital missions with or without ABES installed. Capable of ferry flights with Ferry ABES installed.

Consumable Management Concept Guideline - ABES consumables management required for atmospheric flight regime only. (Orbital mission ABES usage is short duration (2/5 min); ferry mission is long duration and, therefore, is most demanding on CMS.)

- i) RFP Requirement - Orbiter capability to provide for crew survival for 96 hours after an in-orbit contingency, assuming reduced consumption rates, crew in resting level of activity, and vehicle essentially powered down.

Consumable Management Concept Guideline - Accuracy of CMS must be sufficient to provide survival mode management.

- j) Rockwell International Proposal - Performance monitoring approach recommended is autonomous onboard using vehicle displays, controls, software, and selected data.

Consumable Management Concept Guideline - Consumable management functions are similar in instrumentation and displays; CMS should be of similar capability and operational characteristics.

- k) Rockwell International Proposal - Maintenance fault isolation approach recommended is to use a combination of onboard/ground equipment to isolate failure to LRU level.

Consumable Management Concept Guideline - Onboard fault isolation capability implies signals will be available from LRU's which may be used to also provide CMS functions.

- l) Rockwell International Proposal - NASA is expected to develop automated mission planning techniques for operational support.

Consumable Management Concept Guideline - Design should be capable of using automated mission planning system output to perform consumables management.

- m) Rockwell International Proposal - Many missions will be near repetitious, permitting delta planning techniques.

Consumable Management Concept Guideline - Should be able to use canned budgets and loading requirements for most missions.

- n) Rockwell International Proposal - Many payload combinations will require less than maximum system capabilities, permitting greater latitude in planning.

Consumable Management Concept Guideline - Additional consumables can be added on most missions and provide excess capability which reduces the need for extensive consumables management.

- o) Rockwell International Proposal - Flexible subsystem capabilities will relieve criticality of consumables and energy management analyses.

Consumable Management Concept Guideline - Consumable management concept should be compatible with subsystem capabilities to assist when the inherent subsystem design capability is exceeded.

- p) Rockwell International Proposal - Use of tracking and data relay satellites and wideband communications will enhance ground support to payload operations and relieve constraints on critical operations timing.

Consumable Management Concept Guideline - Ground communications capability may be utilized to support consumables management activities to supplement onboard capability.

5.2.2 General Consumable Management Guidelines

The following guidelines were developed from integrating the requirements of several different Shuttle documents to form advanced spacecraft management goals.

Support Goal of Autonomous Vehicle Operation. A program goal of autonomous vehicle flight operation requires that an onboard consumables management capability be provided. However, the complexity of the onboard consumables management system is highly dependent on the degree of vehicle autonomy which is envisioned. For instance a totally autonomous vehicle operation implies that no ground support is required for any mission phase from prelaunch to post landing. On the other hand, highly autonomous operation is provided if the vehicle can operate for extended periods of time while in-orbit with sufficient onboard capability available to deal with contingencies without ground support. There is a significant difference in the onboard system required to provide consumables management for these two classes of "autonomous" vehicles.

Since mission operations in the immediate future will have adequate ground support to supply consumables management assistance during the critical launch and entry operations, it can be assumed that these conditions would limit consideration of autonomous operation to the orbital phases as far as consumables management is concerned.

Reduce Requirements for Mission Ground Support. Manned space flight operations have required extensive ground support to perform consumables management functions such as monitoring consumables usage, updating usage predictions, analyzing discrepancies in usage, and making decisions to effect usage trends. Many of these functions can be performed onboard the spacecraft if the crew is provided with the proper computational aids to perform the necessary operations without devoting an inordinate amount of time to the task.

Reduction of orbital phase mission ground support does not imply that no support will be required for consumables management. But it can mean that consumables personnel will only be required to perform analyses and prediction updates at specified intervals and to remain on call to deal with major problems as the need arises. The frequency of such analyses and updates would be determined by the degree of onboard capability contributing to extended periods of autonomous operation.

Minimize Premission Planning. Providing onboard consumables management capability implies that some provisions for replanning exist onboard. Therefore, the necessity for detailed premission planning on a mission-by-mission basis is minimized since minor plan changes will be readily accommodated by the existing onboard replanning capability. Nominal mission plans may be assembled by the mission planner from categories of events or mission phases, and it is not necessary to provide detailed contingency plans. By this means, the mission planning cycle may be reduced to a short, routine activity as compared to present day methods. However, as will be noted later, the overall accuracy of the onboard consumables management system is directly dependent on the accuracy with which the nominal mission plan describes the actual nominal mission. Therefore, a tradeoff must be made between overall accuracy of the onboard system and simplification of mission planning procedures.

Provides Mission Flexibility. The onboard consumables management capability should support flexibility in scheduling and performing mission events in the most expedient manner. The ability to introduce changes in a mission plan and to immediately assess the impact of such changes on the ability to perform the remainder of the mission with sufficient consumable

reserves available will provide a valuable tool in deriving maximum benefit from each mission. The onboard consumables management system can be designed to support mission flexibility if it is readily useable by crewmen; however, mission flexibility may be impaired if the onboard system is too difficult, complicated, or cumbersome to be used effectively. These considerations demonstrate the necessity for tradeoffs in designing the onboard consumables management system in such a manner as to provide accuracy, extensive management capability, and simplicity of operation.

Reduce Requirements for Crew Training. The onboard consumables management system should provide a simple crew/system interface in order that the crew may readily utilize the information and capability presented by the system. It should not be necessary that the crewmen become experts in vehicle subsystems characteristics in order to operate the consumables management system if the display data presentation is easily interpreted and if the required crew inputs to the computer are kept concise and logical. Attention devoted to the details of the crew interface in the entire consumables management process will result in a system which is amenable to full utilization by the crew without the necessity for extensive training.

Reduce Crew Work Load. The onboard consumables management system should provide assistance to the crew by automatically performing functions which are most demanding in terms of time and effort. Much of the activity associated with consumables management is repetitive, routine, and time consuming. Monitoring parameters, recording data, and checking data for limit violations are functions which would occupy most of the time required for manual performance of consumables management. The routine functions are those which are easily automated and, as a minimum, should be considered for onboard, automatic performance.

Avoid Special Requirements. The Shuttle consumables management concept should be developed in such a way as to avoid special or unique requirements in performing the consumables management functions in order to minimize development and operation costs. Existing subsystem sensors should be used where possible. Display, computing, and data storage requirements should be consistent with those required for other subsystem monitoring functions. Ground support requirements should not be specified solely for performing consumables management functions.

Provide Concept Which can be Easily Modified. Capability for change should be provided as a feature of the Shuttle concept. It should be possible to modify one portion with minimum impact on the remainder of the concept.

Support Shuttle Operational Requirements. The onboard consumables management concept should support specific Shuttle operational requirements such as the following items:

- o Capability for wide range of mission operations
- o Capability to support mission up to 30-days duration
- o Capable of launch from standby status within 2 hours
- o Capable of supporting 96-hour survival mode operation
- o Capable of providing defined consumables support for payloads

5.3 CONSUMABLES MANAGEMENT CONCEPTS

The procedure in developing functional concepts for performing consumables management was started by first reducing the task into basic functional elements in order to simplify evaluation of the advantages and disadvantages of various methods of performing the individual functions. The functions which must be accomplished in the performance of consumables management consist of the following:

- a) Monitoring - Measurement, processing, and observation of subsystems parameters indicative of consumables usage.
- b) Evaluation - Comparison of monitored data to reference values to determine discrepancies between actual and reference values.
- c) Assessment - Determination of causes of detected deviation from nominal, impact of the deviation on the remainder of the mission, and options available to correct for the deviation.
- d) Corrective Action - Measures taken to correct or control consumables usage.

These four functions must be accomplished in order to perform consumables management. Development of concepts for consumables management systems consist of selecting different methods for performing these functions. Factors to be considered in regard to performance of the functions are summarized below.

- a) Monitoring is a repetitive process which must be accomplished in order to initiate performance of the remaining functions. The simple, but routine, nature of the function makes it a strong candidate for automatic performance because it is a very demanding manual activity.
- b) Evaluation is, like monitoring, a very repetitive activity which should be performed frequently. The complexity of the task is entirely dependent on the consumable involved since some comparisons are made against fixed limits while others are made against dynamic limits. However, in most cases the evaluation function is a simple activity for the software to perform automatically.
- c) Assessment is not ordinarily a routine activity as were the two previous functions. Assessment may be required in instances such as pursuing targets of opportunity, scheduling activities beyond those included in the nominal flight plan, and detection of data trends indicative of imminent or eventual limit violations. The assessment function is not easily automated since it involves obtaining data from various sources, evaluating the significance and impact of the data, and making judgemental decisions as the appropriate course of action. For these reasons, assessment is likely to be a predominantly manual function, but the consumables management system may well provide aids for accomplishing the function.
- d) Corrective action is a manual onboard function since there are no plans to provide automatic control of subsystem configuration, nor of the activity scheduling, for the Shuttle vehicle. Capability may be made available in the future which can make it feasible to seriously consider automatic corrective action under certain conditions.

With the functions defined as previously noted, and with the considerations listed above, the development of consumables management concepts consist of determining whether the various activities are to be performed on the ground or onboard, and whether the activities are to be performed manually or automatically.

5.3.1 Concept Descriptions

Development of the concepts for performing consumables management was performed by using a functional module, or building block, approach to describe the various distinct activities performed by the system. This modular approach permitted the use of distinct designations for the various activities and it also simplified the shifting of functional modules between ground and onboard facilities. The modules are defined in the concept descriptions which follow.

The concept descriptions are presented in descending order of onboard complexity. The most complex concept proposed for onboard use is not a highly sophisticated approach as current Shuttle requirements did not make advanced techniques attractive for detailed study. However, several features were investigated which should be considered for future application to consumables management. These features are briefly described separately from the proposed concepts.

Table 5-4 presents principal features of each of the concepts in a form for easy comparison of the different capabilities.

Concept Number 1 Description. The first concept provides the capability to perform all flight related consumables management functions onboard the vehicle. As shown in Figure 5-1., the ground supplied mission plan is processed by the onboard software to produce the required consumables usage profiles, event data, and reference values to be used in performing the consumables management functions.

The more routine functions are performed automatically, but the evaluation and corrective action functions are primarily crew functions. However, various software aids are provided to assist the crew in performing their activities. The different parts of Figure 5-1. are described in detail in this section. In later sections, the other concepts are described only as to differences from that presented for this concept.

Data flow for Concept Number 1 starts with the ground supplied mission planning data which is processed by the onboard software Consumables Prediction Module to produce predictions of mission consumables requirements.

CONCEPT #1	CONCEPT #2	CONCEPT #3	CONCEPT #4
<p><u>FUNCTIONAL OBJECTIVES</u></p> <ol style="list-style-type: none"> 1. Provide high degree of onboard autonomy and replanning capability with high degree of automaticity. 2. Rely on ground to supply premission consumables event timeline and sub-systems data generated in mission planning system. 3. Minimize requirement for crew interaction during periods of high activity. 4. Provide automatic monitoring and warning system to relieve crew of requirements for continuously observing subsystem consumables usage. 	<p><u>FUNCTIONAL OBJECTIVES</u></p> <ol style="list-style-type: none"> 1. Provide high degree of autonomy with moderate degree of automaticity. 2. Same as Concept #1. 3. Crew interaction required for replanning and diagnosing consumables problems. 4. Same as Concept #1. 	<p><u>FUNCTIONAL OBJECTIVES</u></p> <ol style="list-style-type: none"> 1. Non-autonomous system, and low level of automaticity. 2. All prelaunch planning and consumables usage requirements are determined on ground. 3. No software aid for onboard replanning capability; any detailed replanning is accomplished by ground and uplinked to spacecraft. 4. Same as Concept #1. 	<p><u>FUNCTIONAL OBJECTIVES</u></p> <ol style="list-style-type: none"> 1. Onboard functions performed manually and system non-autonomous. 2. Same as Concept #3. 3. Same as Concept #3. 4. No automatic monitoring and warning system. Monitoring is joint ground/onboard responsibility.
<p><u>FEATURES OF CONCEPT #1</u></p> <ol style="list-style-type: none"> 1. Onboard system accepts input of prelaunch data constants and Consumables event timeline, generated by ground mission planning system. 2. Onboard system calculates consumables requirements to end of mission and generates usage profiles. 3. Onboard system compares predicted usage to redlines and constraint limits and alerts crew of any violations. 4. Onboard system compares actual usage to predicted usage and alerts crew of deviations from predicted nominal. 5. Onboard system compares actual usage to constraint limits and automatically alerts crew of violations. 6. Crew provides decision making capability to diagnose failures, potential failures, and corrective action. 7. Crew has capability to perform all levels of mission replanning, but require minimum interaction for special types of replanning. 8. Onboard system provides automatic consumables replanning for certain maneuver/trajectory imposed changes. 9. Ground support not required for normal real time operation. 	<p><u>FEATURES OF CONCEPT #2</u></p> <ol style="list-style-type: none"> 1. Same as Concept #1. 2. Same as Concept #1. 3. Same as Concept #1. 4. Same as Concept #1. 5. Same as Concept #1. 6. Same as Concept #1. 7. Provide capability for crew to perform all levels of replanning by manual interaction with the software. 8. No automatic replanning capability. 9. Same as Concept #1. 	<p><u>FEATURES OF CONCEPT #3</u></p> <ol style="list-style-type: none"> 1. Ground system input of planned usage profiles, redlines, constraint limits, etc. Consumables budgets are computed by ground system. 2. No onboard calculation of consumables requirements. Stored usage profiles entered from ground. 3. All predicted usages are checked for redline and constraint violations by the ground system. 4. Crew performs monitoring of actual usage versus predicted usage to determine deviations from predicted nominal. 5. Same as Concept #1. 6. Same as Concept #1. 7. Onboard replanning capability is limited to using stored usage profiles or onboard charts and applying crew judgement. 8. Same as Concept #2. 9. Ground support required for all detailed replanning functions. May require ground monitoring of usage on a periodic basis to assess the need for update of predictions. 	<p><u>FEATURES OF CONCEPT #4</u></p> <ol style="list-style-type: none"> 1. Same as Concept #3. 2. Same as Concept #3. 3. Same as Concept #3. 4. Same as Concept #3. 5. Both ground and crew have responsibility for monitoring and checking for constraint violations. 6. Diagnosis of failures or violations are the joint responsibility of the ground and crew. 7. Same as Concept #3. 8. Same as Concept #2. 9. Same as Concept #3.

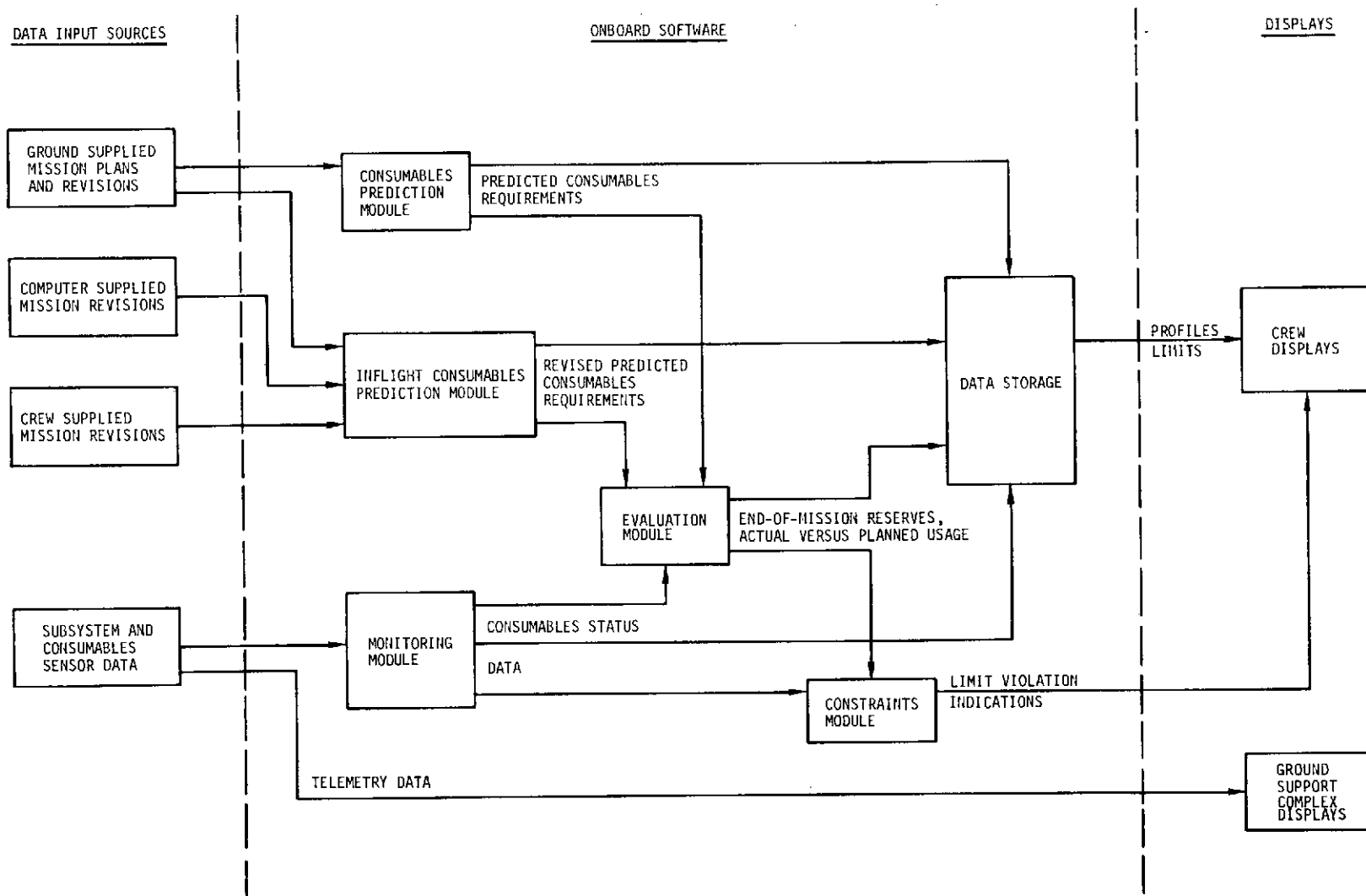


Figure 5-1 Concept Number 1 Block Diagram

The predicted requirements, which are functions of mission time, are used as references for comparison with actual data. During the mission, consumables data from subsystem sensors are processed by the onboard software Monitoring Module to produce the appropriate parameters indicative of actual consumables status. Actual and predicted consumables data are compared in the Evaluation Module to determine the magnitude of differences between the two values. The Constraints Module checks both the indicated differences and the actual consumables data for violations of predetermined limit values. Displays can be selected to present actual and predicted usage profiles, actual consumables status data, and constraint violation indications.

A crew aid is provided for evaluating the impact of proposed mission event and schedule changes on future consumables usage. The Inflight Consumables Prediction Module accepts mission revision data either from crew inputs or from revisions provided as a result of other computer data processing activities. The revised mission planning data is processed to predict consumables requirements for the remainder of the mission. If no constraints are violated, the crew may accept the revised mission for storage and future evaluations will be based on the revised mission data.

Supplemental information to provide additional insight for the first concept theory of operation is presented in the following paragraphs.

Ground Supplied Mission Data - Ground supplied mission planning data provides the input for the onboard consumables management system. Mission events and activity descriptions are required for processing to determine consumables budgets and usage profiles. It is anticipated that there will be many users of the mission planning data in addition to the consumables management system and that ground/onboard system compatibility will be assured.

Consumables Sensor Data - Subsystem instrumentation will provide data for determining status information regarding subsystem performance parameters, consumables quantities remaining, and consumables usage rates.

Crew Supplied Mission Revision - The crew will have the capability to manually enter data to make trial mission revisions and to evaluate the predicted impact of those changes on the remainder of the mission. The input data manually supplied by the crew will consist of addition, deletion, and rescheduling of mission events.

Computer Supplied Mission Revisions - Inflight replanning of mission activities may be automatically evaluated as to consumables requirements in response to mission revisions which are the result of calculations performed in another portion of the onboard software. For instance, a G&N calculation of a rendezvous could supply data such as burn time, burn duration, attitude hold period, etc. This automatic feature not only saves time in evaluating the various consumables requirements involved in a mission revision, but it also reduces the probability of error in the manual entry of data computed and displayed during a previous computation sequence.

Consumables Prediction Module - The purpose of the Consumables Prediction Module is to perform preflight consumables requirement predictions in response to mission planning data supplied by the ground support complex. Processing of the mission plan by the Consumables Prediction Module will yield consumables requirements data in the form of predicted quantity remaining profiles, usage rate profiles, and dynamic and fixed limits. These data then become the references against which actual data is compared until such time that the mission plan is revised and new reference values are computed.

Monitoring Module - Determination of current consumables status is provided by processing subsystem sensor data within the Monitoring Module. Since some sensors provide outputs which are not direct indications of required consumables parameters, calculations may be required to ascertain the value of the required parameters. Quantity and usage rate data which are calculated by the Monitoring Module are provided to crew displays and also to the Evaluation and Constraints Modules.

Evaluation Module - Two primary functions are performed by the Evaluation Module. First, the predicted end-of-mission reserves are calculated to assure that the current mission plan provides adequate reserves to safely complete the mission. Second, comparisons are made between actual

and predicted consumables status data and the difference between the two values is calculated. Both the predicted end-of-mission reserves and the actual/predicted comparison values are provided to the Constraints Modules for limit violation test.

Inflight Consumables Prediction Module - Revised mission planning data is processed in the same manner as preflight mission plans. The Inflight Consumables Prediction Module provides revised consumables requirement predictions for evaluation of acceptability. Revised mission planning data may be supplied from either of two sources. The crew may enter mission revisions by manual inputs which add, delete, or reschedule mission events. Mission revisions may also be supplied from the automatic replanning provision for processing computer supplied data.

Constraints Module - The function of the Constraints Module is to test for limit value violations of specified parameters in order to provide indications to the crew, via the crew displays, that a potential problem exists. Monitoring module outputs are tested for violation of constraints placed on the actual consumables parameters such as quantity and usage rate measurements. Also, the outputs of the Evaluation Module are tested for excessive differences between actual and predicted values and for violations of redlines and end-of-mission reserve constraints.

Concept Number 2 Description. The second concept provides all of the same features described for the first concept with the exception of the provision for automatically accepting computer supplied mission revision data. Revised mission planning data is supplied by either ground or crew input. The block diagram of Concept Number 2, presented in Figure 5-2, shows that the onboard automatic monitoring and constraints testing capabilities are retained as is the capability to generate consumables requirements data by processing ground supplied mission planning data.

Distinctive features of this concept are that only the routine functions are automated, the non-routine activities require crew participation, and the replanning functions are provided onboard. Therefore, this concept will support full onboard consumables management capability without extensive ground support.

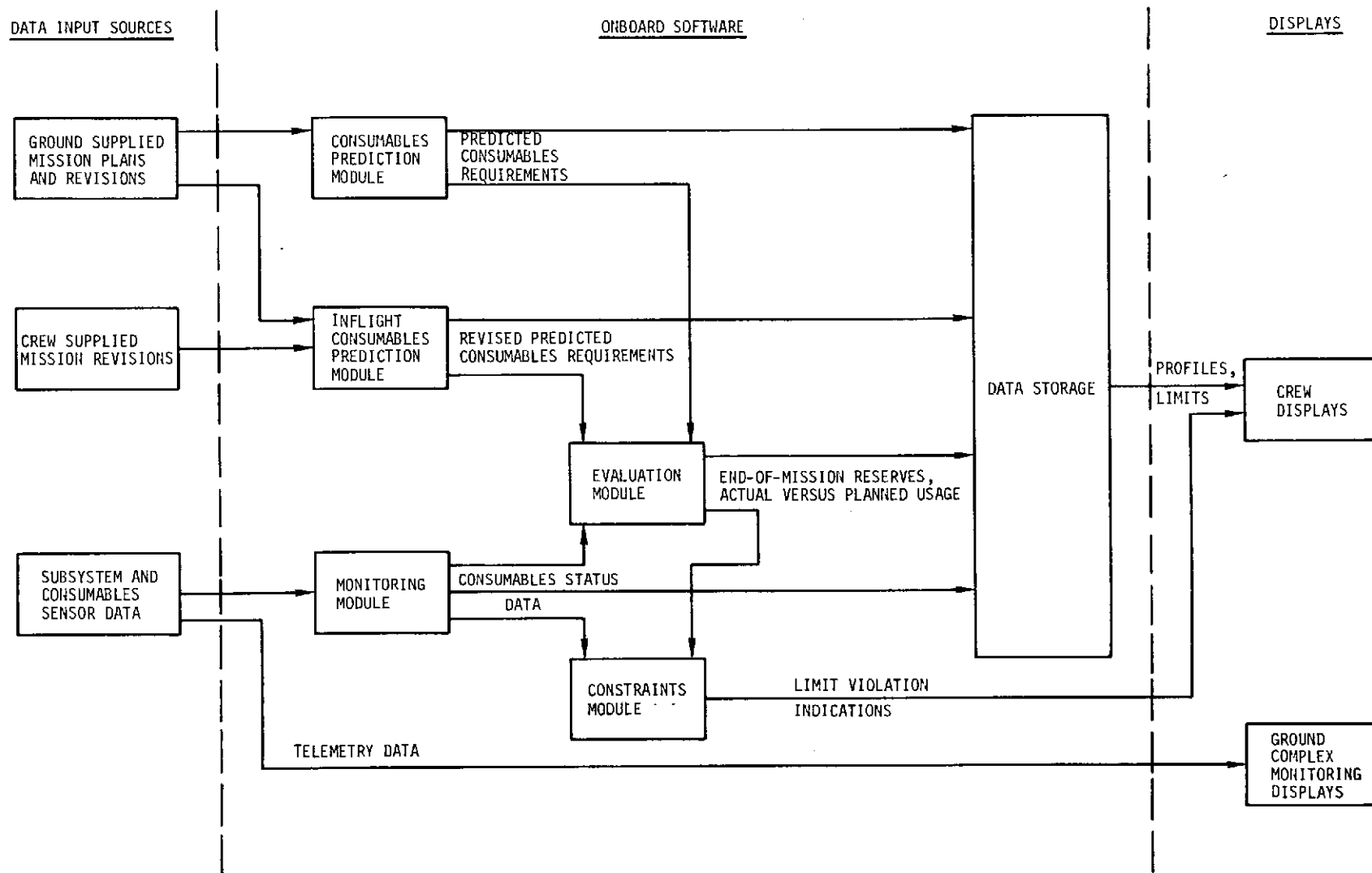


Figure 5-2 Concept Number 2 Block Diagram

Concept Number 3 Description. The third concept provides reduced complexity of the onboard software, with considerably reduced onboard capability, compared to concepts 1 and 2. Figure 5-3 shows that the only functional modules retained onboard the vehicle are the Monitoring Module and the Constraints Module. The onboard system capability is retained to monitor and store actual consumables data for display to the crew. Also, the monitored data is tested for constraint violations with the constraint limits being determined by and entered from the ground system.

Predicted consumables usage profiles will be entered in data storage for display and comparison with actual usage data. The prediction profiles will be determined by ground support and entered prelaunch. Profile revisions may be uplinked from the ground as mission changes require.

There is no onboard provision for replanning or predicting consumables usage. Responsibility for both prelaunch budgeting and real time mission revision evaluation is assigned to the ground support complex. This requirement to update consumables predictions also imposes a requirement for continual ground monitoring of sensor data in order to assess consumables status prior to performing updated analyses.

Concept Number 4 Description. The final concept shown in Figure 5-4, presents the minimum in capability for advanced vehicles which have onboard data storage and display facilities. Nominal usage profiles and redlines are entered in the onboard data storage for display and comparison with actual consumables data. This data will provide the crew with a good indication of how the consumables status compares to both nominal and redline values, and it will be possible to do some limited revisions to the mission if this data is available.

The ground must assume full responsibility for monitoring sensor data and detecting constraint violations as well as performing analyses to support mission revisions. The ground role for this concept will be essentially the same as it was for the Apollo and Skylab programs.

It should be pointed out that this concept can be made to be an effective onboard capability for dealing with contingencies if; 1) the crew has

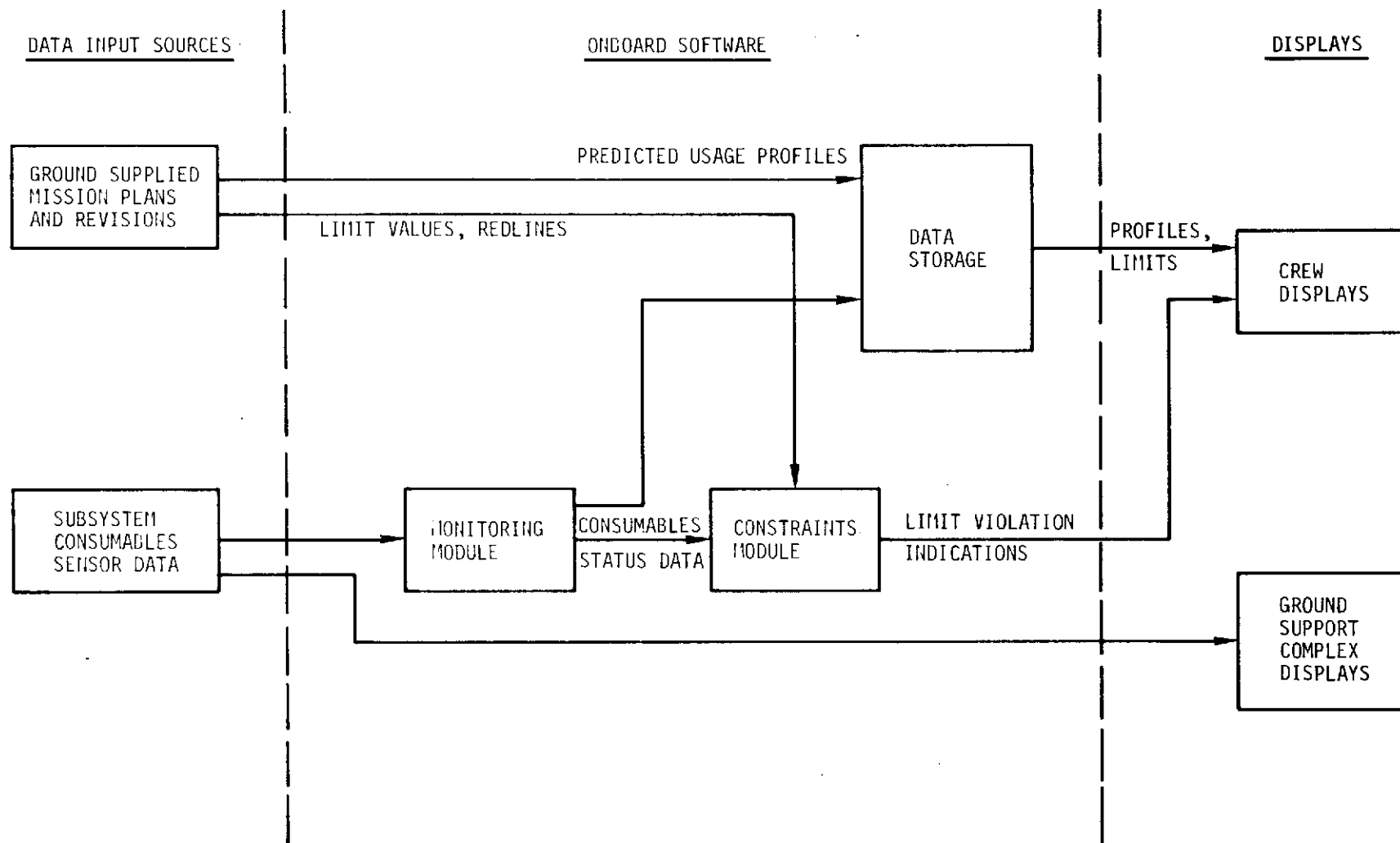


Figure 5-3 Concept Number 3 Block Diagram

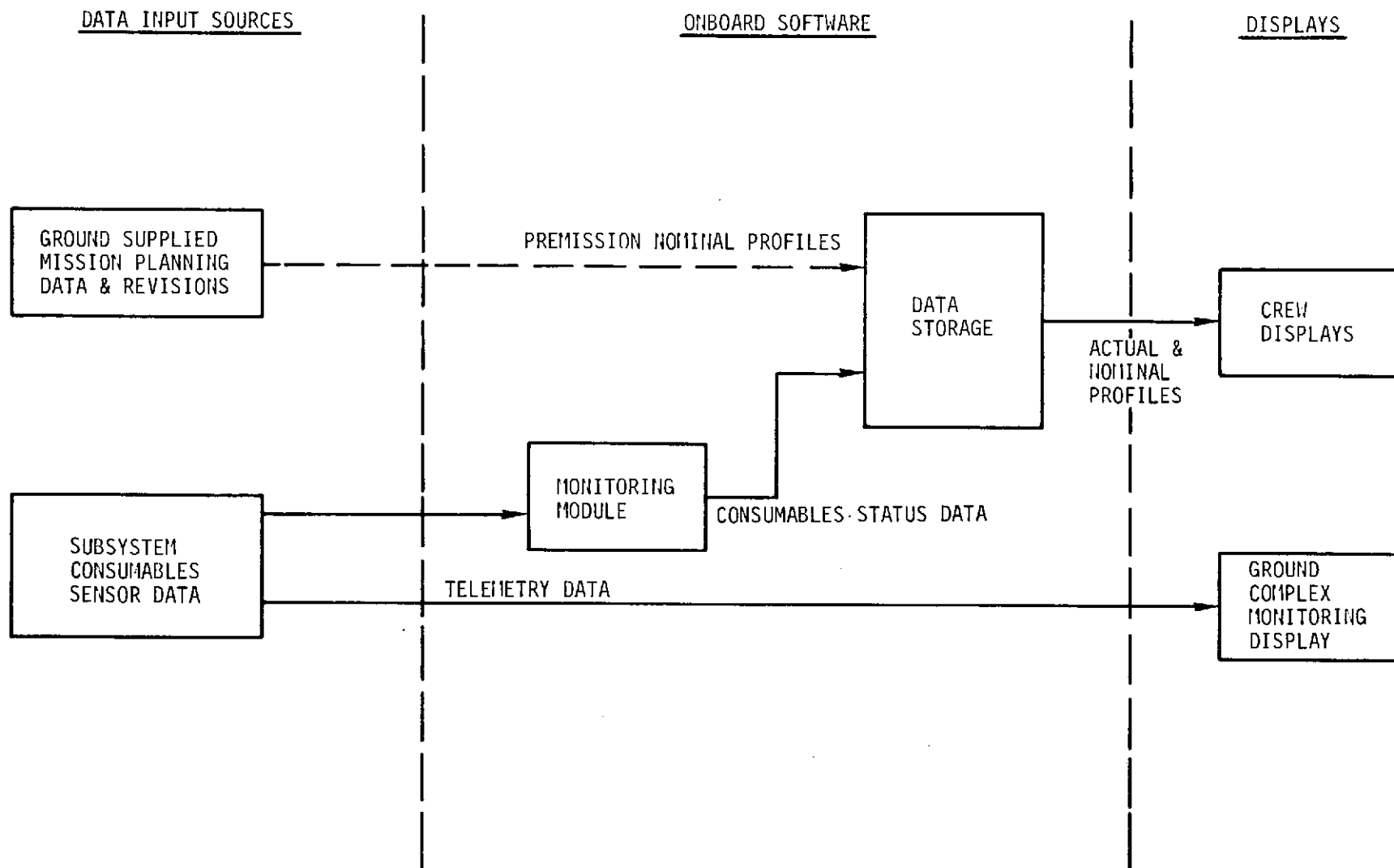


Figure 5-4 Concept Number 4 Block Diagram

extensive training in the subsystems characteristics and consumables performance under off-nominal conditions, and 2) backup capability is provided in the form of crew charts and contingency procedures. With this crew capability and the displays available, a very effective consumables management tool is provided for dealing with contingencies until ground support is available to provide assistance.

5.4 CONCEPT EVALUATIONS

The task of selecting a consumables management concept for a particular application involves performing tradeoffs to determine the features that are justifiable. Some evaluations can be made of the four concepts described in Section 5.3 as to comparative rankings for important selection criteria. It should be emphasized that only relative comparisons can be made for a general evaluation since there are many factors which are specifically program related that will influence quantitative evaluations.

The items which follow present a discussion of important evaluation factors and their significance to the four consumables management concepts. Reference to the concept summary presented in Table 5-4 will assist in observing the features of the various concepts.

5.4.1 Software Requirements

The software required to perform consumables management is the most tangible factor involved in making comparisons of the concepts. It is assumed that onboard software is more costly to develop than is ground software for purposes of this evaluation. Increasing the onboard software requirement results in increasing vehicle development program costs (actual dollar per word costs are entirely program dependent), but vehicle costs must be evaluated against ground software development and operating cost. Therefore, a larger amount of onboard software is considered to be a negative factor in evaluating the concepts, and the resulting relative ranking of the concepts is presented below.

- a) Concept Number 4 - Requires less onboard software than any of the candidate concepts. The only software functions are the monitoring of consumables parameters and storage of data for display. Very few computations are required, so a large majority of the onboard software is devoted to data storage.

- b) Concept Number 3 - The constraints testing provided by this concept requires only slightly more software than Concept Number 2. Additional storage of limit values and the comparison of these limit values to actual data will require additional data storage and logic operations, but no additional computational operations are required.
- c) Concept Number 2 - Significant increases in computational software are required to perform the prediction and evaluation functions provided by this concept. However, the data storage requirements, which are essentially the same as Concept Number 3, are still large compared to the computational software required to perform the additional prediction and evaluation functions.
- d) Concept Number 1 - The automatic replanning capability provided by accepting computer supplied mission revision data represents a very small increase in software requirements relative to Concept Number 2. There is no difference in any of the functions performed; the difference is in the source of the mission revision input data.

A study of the proposed Shuttle concept was performed in order to obtain some quantitative estimates of software requirements for managing each of the Shuttle consumables. Volume II of this report gives an indication of the differences in onboard software required to provide the various levels of capability described for the above concepts.

5.4.2 Hardware Requirements

There are no differences in hardware requirements for the four concepts, so no ranking can be made. Each concept requires the same subsystem sensors to present subsystems data regardless of whether the data is used by the ground complex, the crew, or the onboard computer. Likewise, each concept requires the same display hardware to provide the capability specified for conveying information to the crew.

5.4.3 New Technology Requirements

New technology, in terms of advanced state-of-the-art requirements, is not a factor in evaluating any of the consumables management concepts. Hardware requirements impose no requirements for advanced technological capabilities. Software requirements impose no requirements exceeding present day capability. The primary task is one of adapting more general ground support software models to the onboard software special applications.

5.4.4 Mission Flexibility

Mission effectiveness is increased by providing the crew with the capability to rearrange the mission schedule, add or delete events, and add or delete activities. Such replanning capability will increase mission flexibility by supporting expeditious onboard action in performing activities at the time, and in a manner, that maximizes mission effectiveness. The crew can usually make a better assessment of their ability to improve mission effectiveness than can the ground support personnel. Therefore, aiding the crew in making such assessment will increase mission flexibility.

A word of caution should be added in regard to the relationship between onboard consumables management capability and mission flexibility. A consumables management system must be designed such that it is easily utilized as a crew aid in order to promote mission flexibility. A system which is too difficult to use will require an inordinate amount of crew attention and the consequences are that mission flexibility is hindered rather than helped. For purposes of evaluation, it will be assumed that the concepts will be implemented with due attention given to the crew/system interface so that good system utility is assured.

- a) Concept Number 1 - Greatest flexibility is afforded by this concept which provides the best aid to the crew for performing revised mission activities. The automatic replanning feature for certain types of mission revisions will greatly assist the crew in assessing the feasibility of proposed mission changes.
- b) Concept Number 2 - Good support of mission flexibility is afforded by this concept which provides full capability for determining the impact of mission revisions on consumables requirements. The absence of the automatic replanning feature results in a slightly lower ranking for this concept.
- c) Concept Number 3 and Number 4 - Both of these concepts are limited in contributing to mission flexibility since both require ground support to perform any replanning. This requirement for ground communications must be viewed as a factor which limits mission flexibility.

5.4.5 Crew Workload

There are two aspects of the proposed concepts which serve to decrease the workload imposed upon the crew in the performance of consumables management. First, those concepts which provide the greatest aid to the crew will obviously decrease the resultant crew workload. Second, assignment of consumables management responsibility to the ground support complex also reduces the crew workload. Considering both of these factors results in the rankings which follow.

- a) Concept Number 3 - The lowest crew workload requirements are imposed by this concept due to the fact that all of the replanning functions are performed by the ground support complex and all of the monitoring and constraint tests are performed automatically by the onboard system.
- b) Concept Number 1 - Increased crew involvement is required in order to accomplish the onboard mission replanning functions. However, when it is realized that the onboard replanning activities will occupy only a very small percentage of the total mission time, it is apparent that the time spent in performing mission revisions will be limited. In addition, the crew aids and automatic features provided by this concept will greatly reduce the necessity for extensive crew attention to consumables management activities.
- c) Concept Number 2 - The crew aids provided by this concept allow the consumables management functions to be performed without placing excessive workloads on the crew. The lack of the automatic replanning capability, which is provided by Concept Number 1, results in a slight increase in crew workload with this concept.
- d) Concept Number 4 - Although the ground performs replanning activities under this concept, which serves to reduce the crew workload, the ground and crew have concurrent monitoring responsibility which results in a significant increase in crew activity. Furthermore, situations when ground communication is not available it places full monitoring responsibility on the crew. The monitoring activity is not a difficult task, but it is a repetitive, demanding activity which significantly increases the crew workload.

5.4.6 Crew Training Requirements

The crew must be trained to perform some degree of onboard consumables and subsystem management, regardless of the concept selected, because any loss of ground communication can force the crew to perform consumables management without ground support. Therefore, those concepts which do not provide crew aids for performing onboard consumables management must require more crew training in order to prepare for operation under conditions without ground support. Conversely, the concepts which provide the most onboard assistance to the crew will require the least amount of crew training in consumables management.

- a) Concept Number 1 - This concept provides the most assistance to the crew and, as a result, requires the least crew training. Capability to provide all essential information to the crew in a form which is readily useable will simplify the crew training procedure. Also, the availability of automatically performed functions allows the crew to utilize the system without extensive training.
- b) Concept Number 2 - The amount of crew training for this concept is about equal to concept number 1; the automatic replanning capability is not provided which might require a slight increase in training requirements.
- c) Concept Number 3 - A considerable increase in crew training is required for this concept since no replanning assistance is provided. This means that for emergency situations a backup manual capability must be provided, such as crew charts, which the crew must be trained to use.
- d) Concept Number 4 - This concept represents only a slight increase in crew training requirements over that required by concept number 3. Some additional training would be required in order for the crew to be aware of the various limits on all of the consumables parameters and to recognize violations of constraints when they occur.

5.4.7 Consumables Management System Accuracy

Evaluating the accuracy of a consumable management system requires consideration of subsystem sensors, ground software, onboard software, displays and human factors. Obviously, it is impossible to generalize all of these factors in making concept evaluations, but some judgement can be made as to relative software accuracy, which is of primary importance to this evaluation.

Comparison of the concepts with regard to software accuracy involves comparing ground and onboard software. It must be assumed that the ground complex has more computing facilities and is therefore capable of providing more sophisticated models which provide greater computational accuracy than the onboard system.

Another major source of error between actual and predicted consumables usage is the difference which results from the actual mission differing from the planned mission on which the predictions were based. These sources of error are often very difficult for the ground to detect since they have incomplete knowledge of all the activities onboard this vehicle. On the other hand, the crew knows exactly what occurs onboard and how the mission differs from the plan. This factor weighs in favor of onboard accuracy exceeding ground accuracy.

Considering both of the factors discussed, and also considering the sources of error experienced during Apollo and Skylab missions, results in the concept ranking of relative accuracy which follow.

- a) Concept Number 1 and Number 2 - Both concepts are rated equally since each concept employs the same software for performing the consumables management functions. Although the onboard software accuracy will suffer somewhat from the simplified models employed, the onboard capability to keep closer agreement between predicted and actual values by updating predictions in accordance with mission revisions causes these concepts to have a higher relative accuracy ranking.
- b) Concept Number 3 and Number 4 - The dependence on ground support to provide all consumables requirement predictions is a common feature of both of these concepts, therefore, they are rated equally. Previous experience shows that the better computational accuracy provided by the ground complex is not sufficient to overcome the errors caused by the actual versus planned mission differences.

5.5 SHUTTLE CONSUMABLES MANAGEMENT CONCEPT

The Shuttle subsystems which employ consumables in their operation were investigated and those consumables which showed potential for management were identified as candidates for inclusion in the consumables management system. The consumables identified in Table 5-5 are those for which a requirement for management exists and for which methods have been identified

Table 5-5. Shuttle Consumables for Management

SUBSYSTEM	CONSUMABLES	Mission Phase Required				COMMENTS
		Ascent	Orbital	Entry	Atmospheric	
Auxiliary Power Unit	Hydrazine	x		x	x	Short duration usage during ascent and entry/landing phases. Monitoring for leak detection during orbital phase.
	Cooling Water	x		x	x	
Environmental Control and Life Support System	Oxygen	x	x	x	x	Most consumables required for crew safety throughout all mission phases. Continual consumables management capability required.
	Nitrogen	x	x	x	x	
	Ammonia			x	x	
	LiOH Cannisters	x	x	x	x	
Cryogenic Storage System	Water	x	x	x	x	Supplies fuel cell hydrogen and oxygen and ECLSS oxygen for all mission phases. Essential for all mission phases.
	Hydrogen	x	x	x	x	
Main Propulsion System/External Tanks	Oxygen	x	x	x	x	Short duration usage. Management of consumables is not required.
	Liquid Hydrogen	x				
Reaction Control System	Liquid Oxygen	x				Required for attitude and three axis translation control during orbital phase. Provides attitude control for early entry phase.
	Monomethylhydrazine		x	x		
Orbital Maneuvering System	Nitrogen Tetroxide		x	x		Required for orbital maneuvers and deorbit.
	Monomethylhydrazine		x			
Orbital Maneuvering System	Nitrogen Tetroxide		x			Required for orbital maneuvers and deorbit.
	Monomethylhydrazine		x			

to influence usage. Not all consumables require the same degree of management and, therefore, a management concept was developed according to requirements for each consumable. As indicated in Table 5-6, the management concept selected for each consumable can be shown to correspond closely to one of the four general concepts described in Section 5.3. Thus, the consumables management system proposed for the operational Space Shuttle is a composite of the general concepts developed under this study.

It should be emphasized that the proposed Shuttle consumables management concept represents a system to support the fully operational Shuttle vehicle. It is recognized that a number of the features which are shown as performed by the software may actually be initially implemented for manual or ground performance and then later implemented within the software according to a phased development plan. The functional modules which are used to describe the concept functions may also provide an effective means for describing the increments by which a phased development plan would progressively increase the onboard capability for consumables management.

In order to provide a consumables management system which is consistent with the Shuttle objectives and operational procedures, extensive effort was made to determine those factors which should be considered in developing the Shuttle consumables management concept. Factors which have been widely expressed, and which influenced the concept development, are listed below.

- a) The crewmen will be active participants in the consumables management process; therefore, they should be provided with the appropriate aids to facilitate performance of consumables management tasks.
- b) There will be active ground participation in consumables management during the critical mission phases for which the ground support complex will be fully manned. These periods include launch and entry/landing as a minimum.
- c) The management concept for each consumable should be developed with regard to its managability and criticality. This may dictate significantly different concepts for the various consumables.
- d) Crew use of onboard replanning capability will normally consist of minor mission revisions. Ground support may provide the analysis and predictions required for extensive mission changes.

Table 5-6 Relation of Shuttle Consumables Management to General Concept

CONSUMABLE	SIMILAR TO GENERAL CONCEPT	PRIMARY CONTROL OF USAGE
ECLSS Ammonia	Concept Number 1	Electrical power loads
ECLSS Nitrogen	Concept Number 1	Mission duration, cabin pressurizations and avionics compartment purge
ECLSS Water	Concept Number 3	Schedule dump and sublimation for non-interference with experiments
ECLSS Oxygen	Concept Number 1	Mission duration, cabin pressurizations and avionics compartment purge
ECLSS Lithium Hydroxide	Concept Number 1	Mission duration or alter change out cycle
FCCS Oxygen	Concept Number 1	Electrical power loads
FCCS Hydrogen	Concept Number 1	Electrical power loads
MPS/ET Propellant	Concept Number 4	Vehicle/payload mass and boost trajectory No real-time control planned
CMS Propellant	Concept Number 1	Delta-velocity for maneuvers
RCS Propellant	Concept Number 1	Maneuvers, maneuver rates, attitude hold deadbands
APU Fuel	Concept Number 3	Subsystem operation duration
APU Cooling Water	Concept Number 3	Subsystem operation duration

- e) The Shuttle flight test program will provide sufficient test data to support the development of simplified software models prior to the operational phase of the Shuttle program.

The subsystem consumables management concept descriptions reflect the influence of these factors in selecting the recommended features.

5.5.1 Consumables Management System Operation

A general description of the sequence of operations involved in performing consumables management for the Space Shuttle are presented in functional flow chart form in Figures 5-5 through 5-7. The system described is similar to the General Concept Number 1 described in Section 5.3. The precise operations vary somewhat for each consumable, but the theory of operation is applicable to management of all subsystems consumables which require onboard capability for replanning consumables usage.

The premission consumables analysis and evaluation sequence is illustrated in Figure 5-5. The onboard software processes a consumable event timeline to determine consumables requirements both as functions of mission time and as total quantities required for the planned mission. The predicted consumables quantities required are compared to actual loaded quantities for acceptability.

The monitoring and evaluation sequence performed during the mission is shown in Figure 5-6. Nominal operations will consist of comparing actual consumables quantities with predicted quantities in order to verify that consumables usage is preceding as planned. In the event that out-of-tolerance conditions are detected, the crew is called upon to determine both the source of the deviation from nominal and the necessary corrective action. It is important to note that this phase of the consumables management process relies on the crew to utilize consumables data, subsystems performance and configuration data, and mission plans/schedule data to assess and initiate the proper course of action. After a course of action is decided, it may be necessary to generate an updated set of predicted usage profiles to describe the effect of mission revisions.

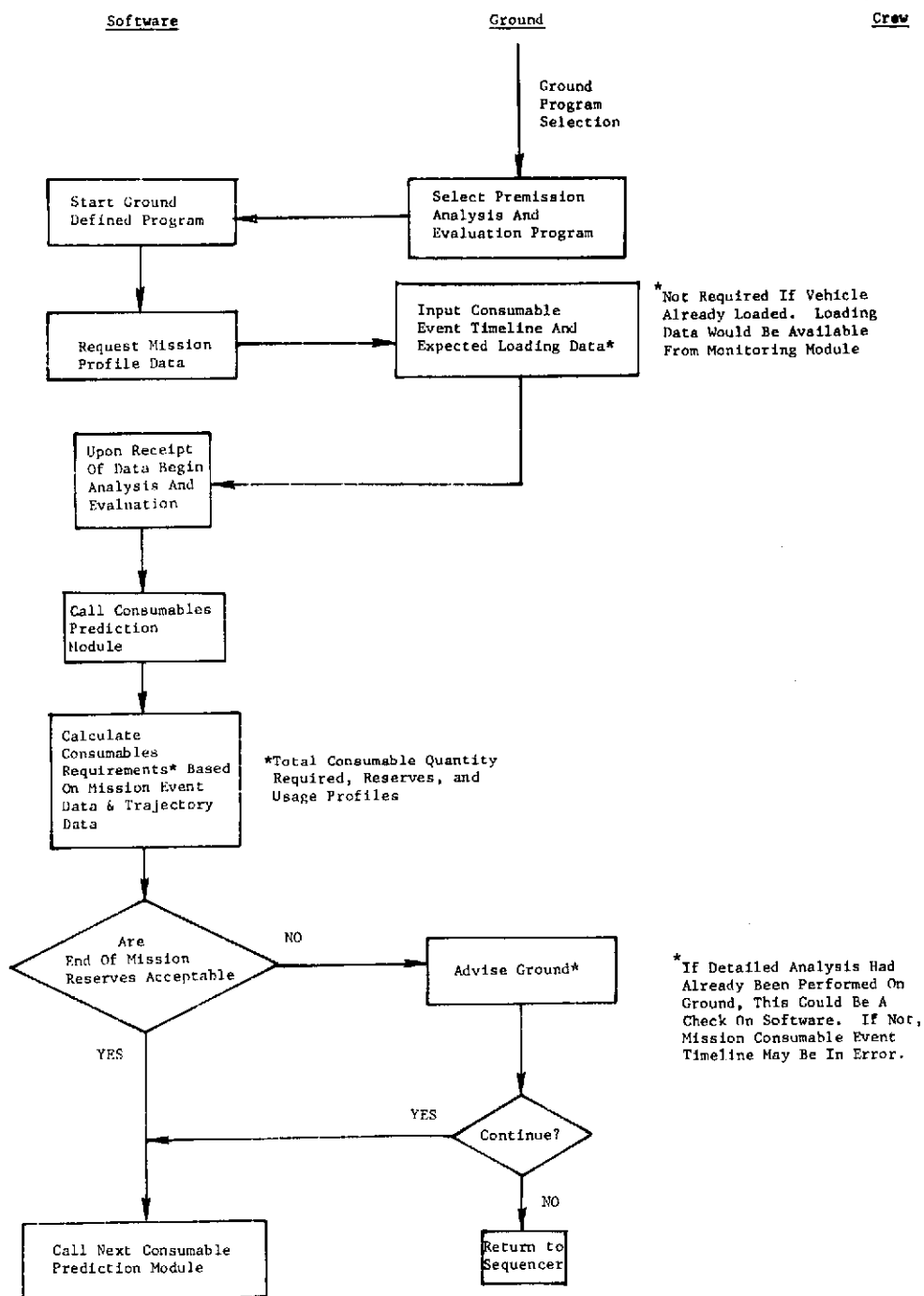


Figure 5.5 Prepermission Analysis and Evaluation Sequence

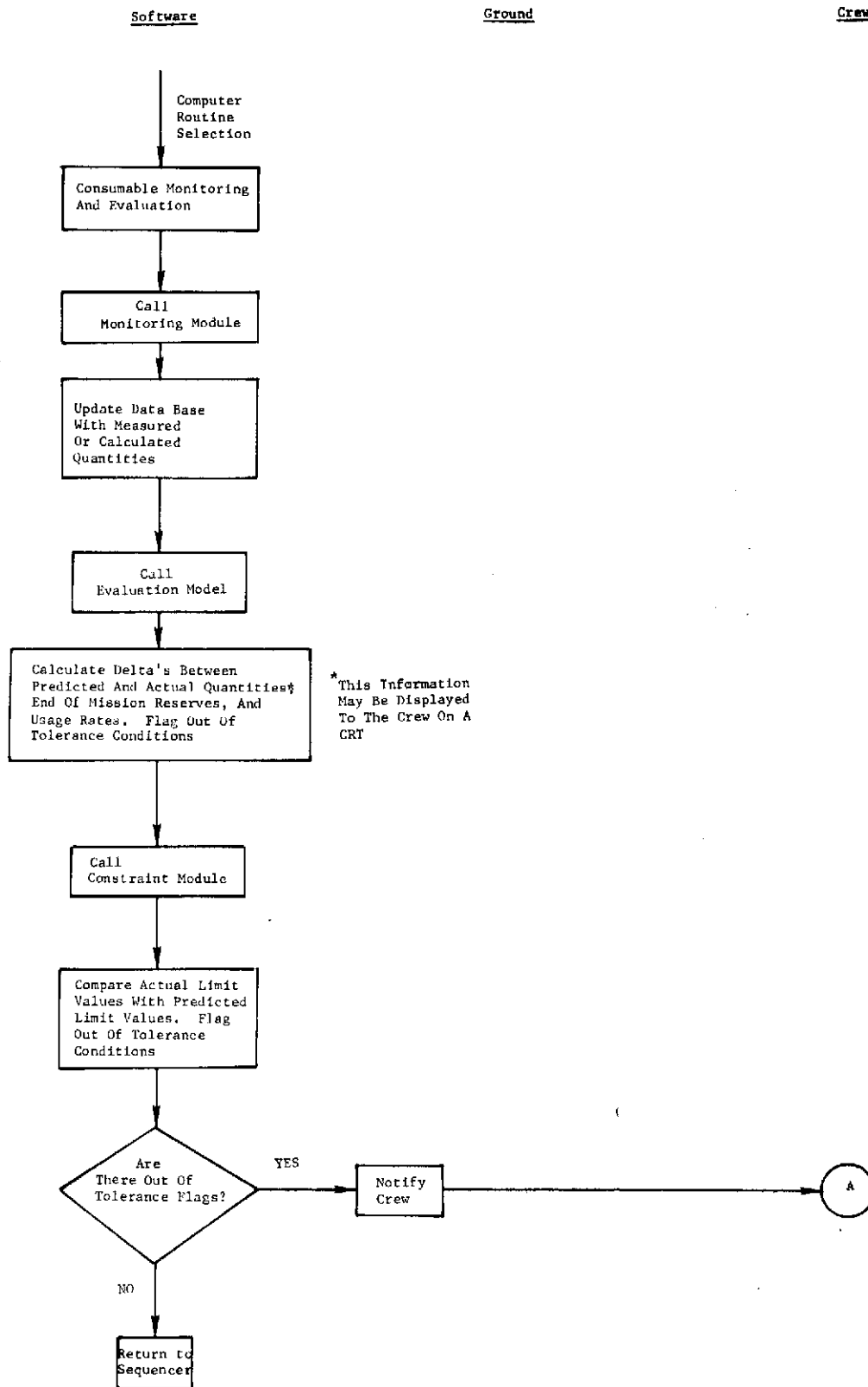


Figure 5-6 Inflight Monitoring and Evaluation Sequence

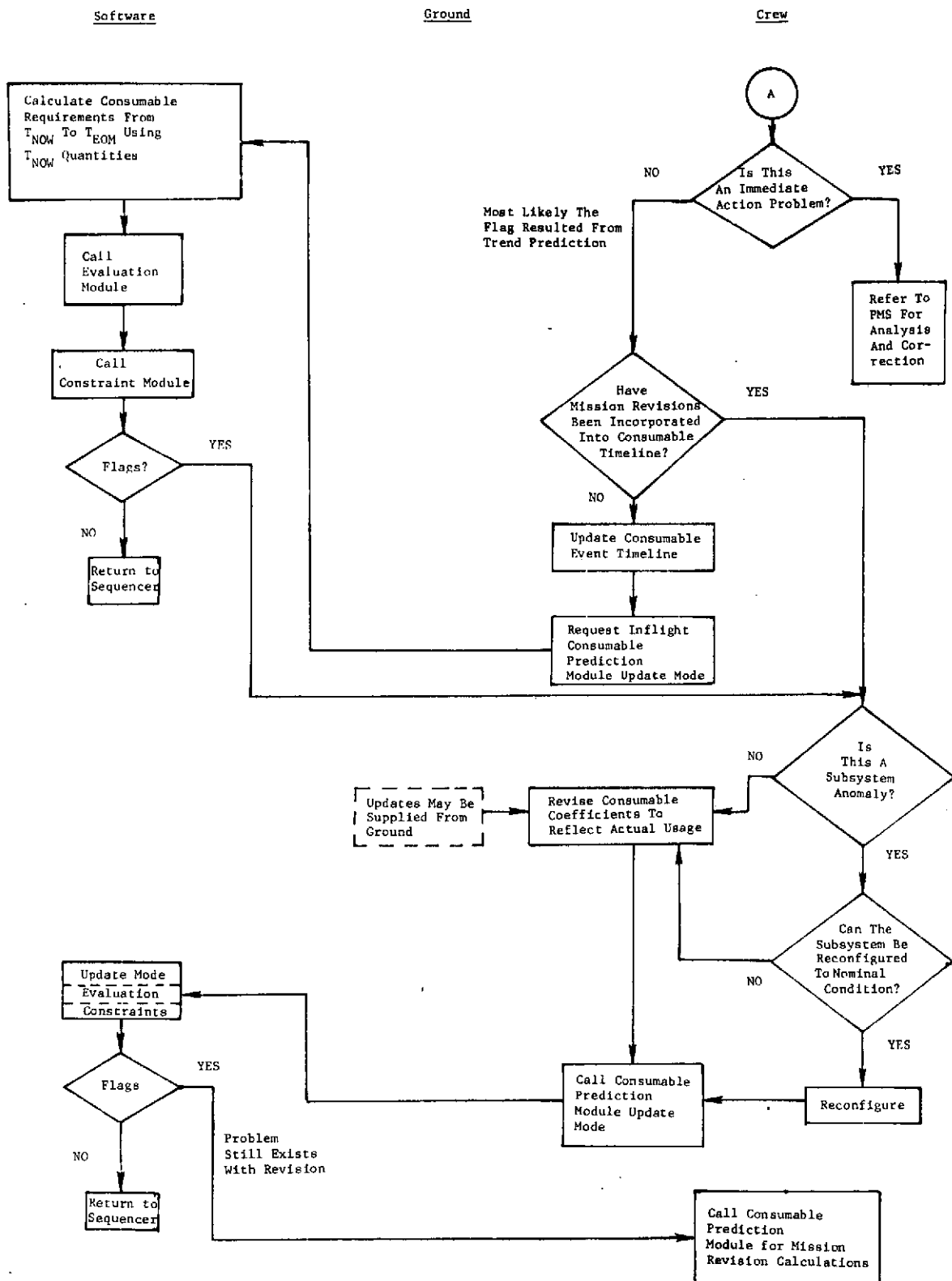


Figure 5-6 Inflight Monitoring and Evaluation Sequence (Continued)

The mission revisions sequence shown in Figure 5-7 may be performed throughout the mission for several different reasons. First, the predictions of end-of-mission reserves become more accurate throughout the mission due to the shorter prediction period, so periodic updates may be performed to determine end-of-mission reserves based on actual quantities as initial conditions. Second, revisions to the mission plan may be evaluated as to impact on consumables usage and either rejected or accepted for inclusion based on predicted consumables requirements. Finally, if usage deviates significantly from nominal values it is desirable to shift the predicted usage profiles so that the usage prediction is initialized at current actual values. This update mode does not involve making revisions to the mission plan, it simply involves making the prediction start at the conditions existing at the present mission time.

5.5.2 Shuttle Subsystem Consumable Management Descriptions

Candidate subsystems were identified for inclusion in the Shuttle consumables management system by evaluating each subsystem which employs expendables as to its capability to be managed or controlled. There are subsystems whose consumables are not readily controllable, such as the solid rocket motor propellant, and therefore cannot be considered for consumables management. Other subsystems were identified which have very limited controllability of consumables usage and which do not merit elaborate management techniques. Several subsystems are used in such a manner that their consumables usage is readily manageable, and techniques to assist the crew in the consumables management process can be accomplished without imposing unrealistic requirements in terms of software or hardware.

The Shuttle subsystems of interest for consumables management are identified in the following subsections with pertinent comments as to the considerations which influence selection of consumables management techniques. The management technique for each consumables is compared to the general concepts described in Section 5.3. Reference to Table 5-4 will provide a useful summary of the general concept features.

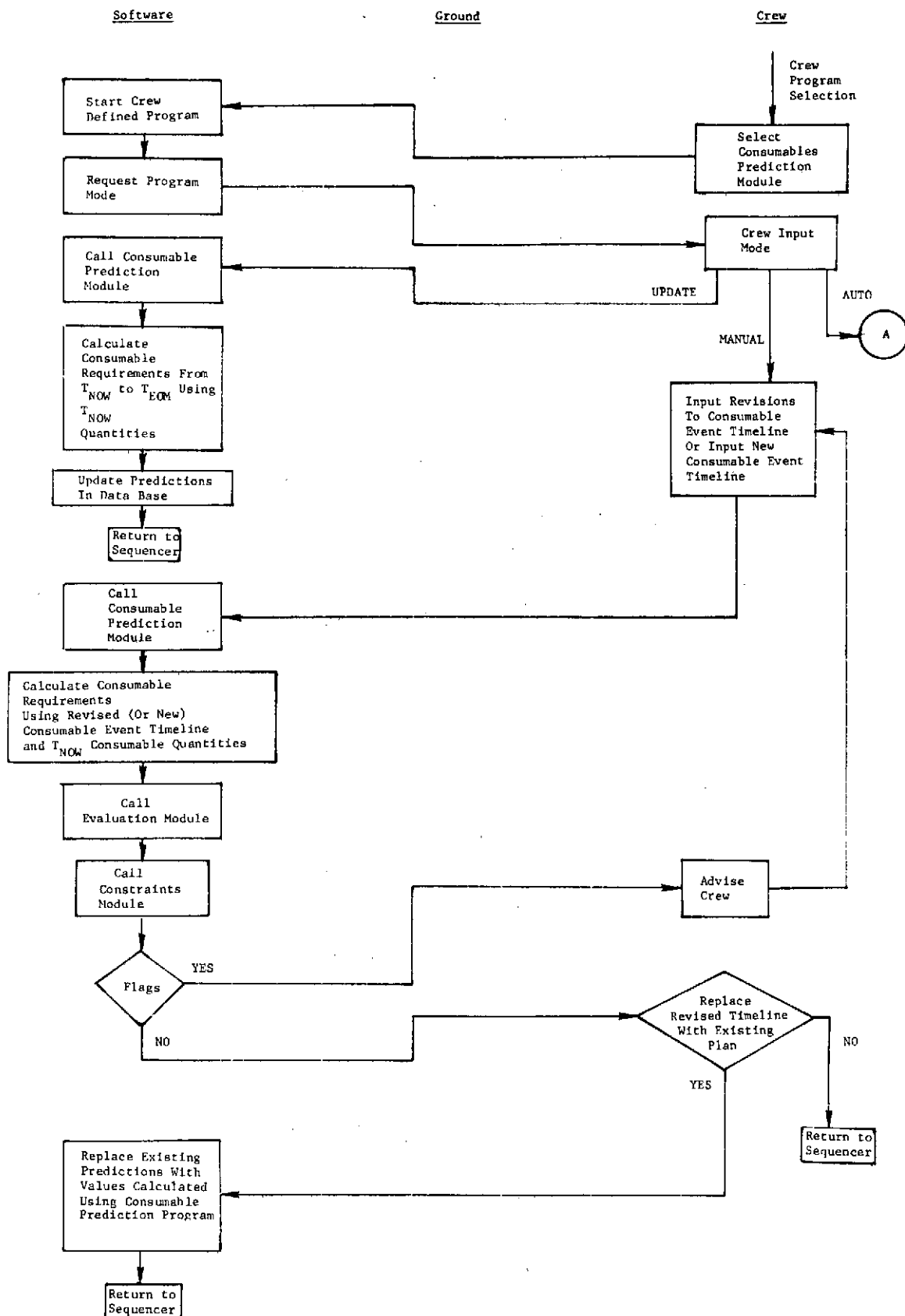


Figure 5-7 Inflight Mission Revision Sequence

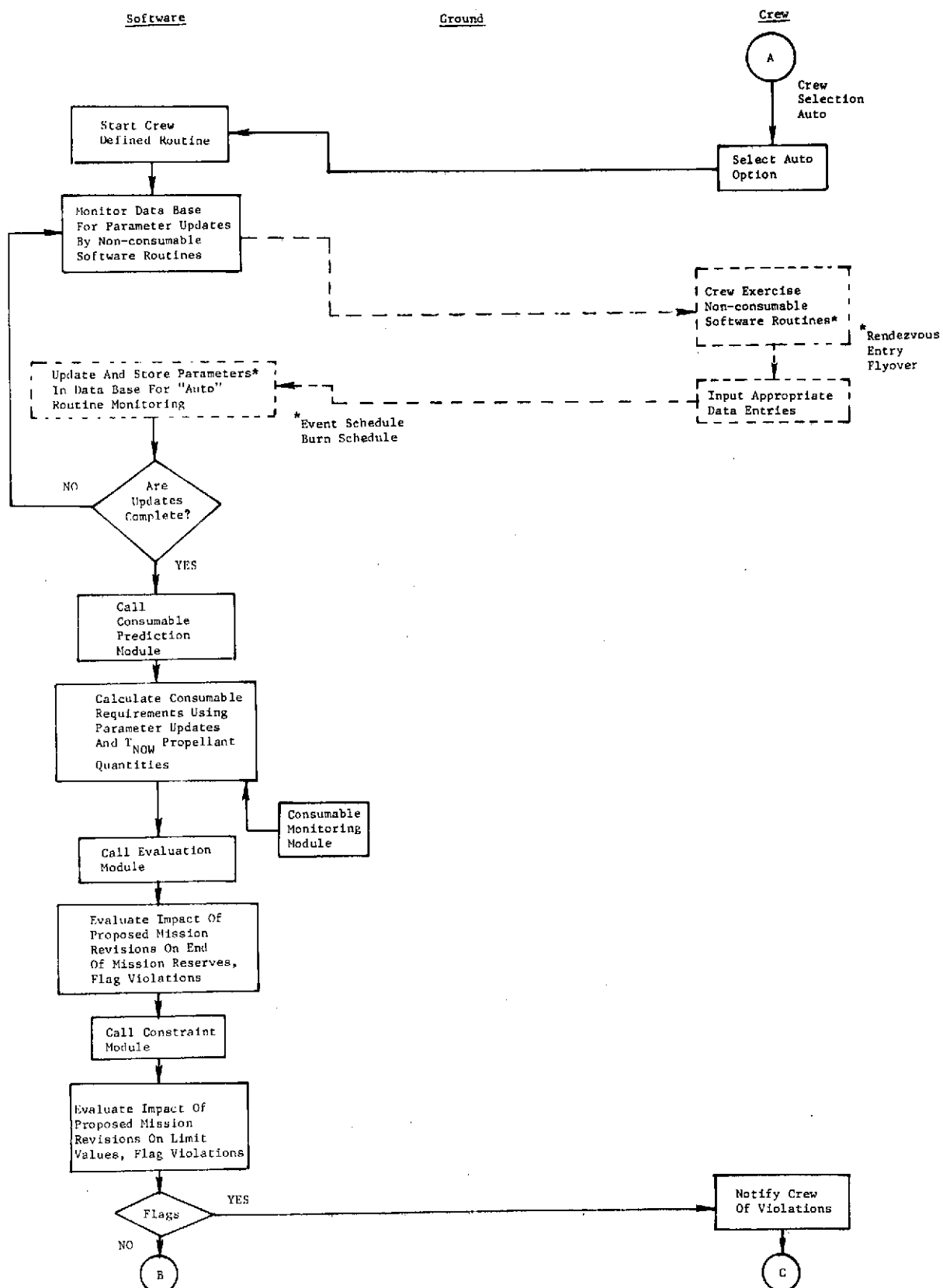


Figure 5-7 Inflight Mission Revision Sequence (Continued)

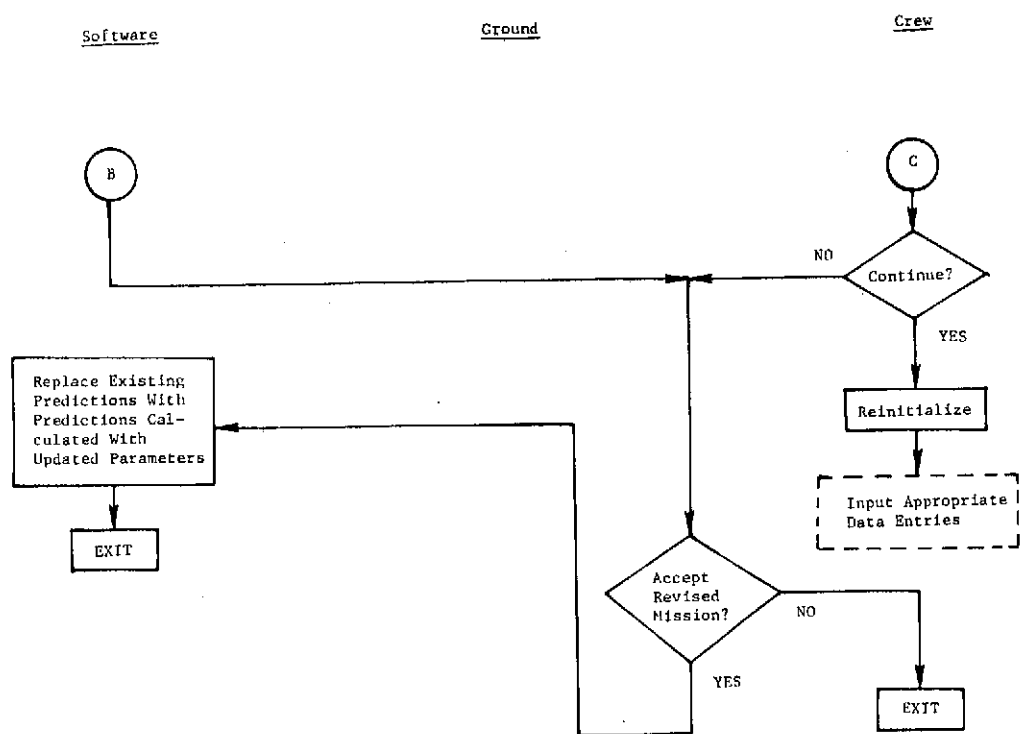


Figure 5-7 Inflight Mission Revision Sequence (Continued)

Auxiliary Power Unit (APU). The APU's are operated to supply hydraulic power only during the ascent and entry/landing mission phases. The limited duration of APU operation also limits the controllability of usage of the consumables which are hydrazine fuel and cooling water. However, due to the fact that APU operation is mandatory for completing the entry/landing mission phase, it is essential that at least the monitoring and evaluation functions of consumables management be provided during the orbital mission phase in order to exercise the option for early mission termination in the event that consumable leakage is detected.

Preliminary analyses indicate that APU operating time is the dominant factor in determining consumable usage. Therefore, for a defined ascent and entry profile, the consumables usage can be predicted by premission analysis and a usage profile generated for comparison with actual quantities available during a mission. During on-orbit operations, monitoring of consumables quantities will be performed in order to assure that no leakage occurs and that adequate quantities are available for completing the planned entry/landing phase. The proposed monitoring, evaluation, and limited replanning capability makes the APU consumables management similar to General Concept Number 3.

Environmental Control and Life Support Subsystem (ECLSS). The ECLSS consumables which require management are nitrogen, oxygen, lithium hydroxide, ammonia, water, and biocide. The degree and form of management is determined by the role of each consumable in supporting the crew health and survival and other subsystem operation.

Oxygen, nitrogen, lithium hydroxide, water, and biocide are consumables which are required for crew health and survival and must therefore be managed to assure that adequate quantities are available to support the mission requirements. The biocide system is not yet adequately defined to determine a method or even a firm requirement for management. It is listed here because it should be considered a candidate for management until requirements can be better evaluated.

Ammonia and water are used to provide cooling for limited periods of time. These consumables must be monitored to assure that adequate quantities are available to meet potential cooling requirements.

The role of the ECLSS, which is to support the crew and other subsystems operation, limits the managability of its consumables. However, ECLSS consumables are essential to crew safety and vehicle operation and must therefore be managed to the extent possible in order to assure that adequate quantities are available to support the mission.

Oxygen and nitrogen provide a two-gas atmosphere at a nominal pressure of 14.7 psia. Crew compartment pressurization, leakage, and waste management purges constitute the principal users, and in addition, the oxygen is used for metabolic consumption. The primary management function is to monitor oxygen usage rate and nitrogen quantity remaining and to evaluate the capability to support the remainder of the planned mission. The consumables management capability provides for monitoring, evaluating, and replanning oxygen and nitrogen usage. Since usage is primarily determined by mission time and pressurizations, automatic replanning can be readily provided. Therefore, the proposed management concept is similar to General Concept Number 1.

The Atmospheric Revitalization Subsystem employs two lithium hydroxide replaceable cannisters which operate simultaneously in removing carbon dioxide from the cabin atmosphere. Alternate cannisters are replaced at fixed intervals under normal operation. For this reason, the management function is simply to monitor the change cycle and to evaluate the capability to support the planned mission with the number of cannisters available. Capability is provided to alter the change cycle if necessary in order to extend the cannister usage interval. The proposed management concept is similar to General Concept Number 1.

Water is a unique consumable in that it is generated onboard as a by product of fuel cell operation. Water is used for crew metabolic consumption, hygienic purposes, and for supplementary cooling purposes. The management problem is twofold in that a sufficient minimum quantity must be available at all times, and dump and sublimation periods must be scheduled for

non-interference with mission activities in order to dispose of excess quantities. The proposed consumables management capability permits monitoring water quantities and usage rates and determining dump and sublimation periods. The proposed water management technique is similar to General Concept Number 3.

Ammonia is used to provide cooling during atmospheric flight of the entry/landing phase. The management function is primarily one of monitoring the ammonia quantity during orbital operations to assure that an adequate supply is available to complete the planned entry/landing phase. The ammonia management is similar to General Concept Number 1 since automatic replanning capability is provided.

Biocide is stored as a liquid and is used as a disinfectant in the urine disposal system. The storage, dispensing, and gauging techniques have not been adequately defined at this time to allow a definite recommendation for management. If management is required, it is anticipated that only monitoring of biocide quantity remaining will be required in order to determine usage rate and projected requirements to the end of mission. A management technique similar to General Concept Number 1 or Number 2 could probably be implemented quite easily.

Fuel Cell and Cryogenic Storage (FCCS). The fuel cells, which supply vehicle electrical power for all mission phases, consume oxygen and hydrogen as reactants which are supplied from the cryogenic storage system. In addition, the ECLSS oxygen is also supplied from this storage system. Another function which involves the FCCS in consumables management is the production of water as a by product of fuel cell operation; the water is managed as a consumable by the ECLSS system.

The continuous essential role of the cryogens in vehicle operation makes the FCCS a strong candidate for inclusion in the consumables management system. An additional significant factor is the capability to control cryogen usage by managing electrical power consumption. For these reasons, a very significant consumables management capability is feasible for the FCCS.

Management of cryogen usage is accomplished by controlling the fuel cell electrical power loads which are functions of mission events and activities. Since electrical power loads can be changed easily during the mission, management of cryogenic consumables is important in fulfilling nominal and revised mission objectives. Full consumables management capability for monitoring cryogen quantities, evaluating consumables status, and predicting new requirements is provided by the proposed management concept which is similar to General Concept Number 1.

Main Propulsion System/External Tank (MPS/ET). The MPS/ET consumables are liquid oxygen and liquid hydrogen. The limited period of MPS operation, which is confined to the launch/ascent phase, severely limits the capability to manage consumables usage. Even more significant, the proposed operational philosophy of loading the external tanks to capacity for all missions almost excludes any necessity for an onboard consumables management capability.

The only consumables management function proposed for the MPS/ET is the monitoring function which serves to make information available to the crew, on an optional basis, regarding the remaining delta-velocity capability provided by the propellant remaining in the external tanks. This concept is similar to General Concept Number 4.

Orbital Maneuvering System (OMS). OMS operation provides propulsive thrust for performing orbital translational maneuvers and for deorbit. Nitrogen tetroxide and monomethyl hydrazine are the consumables employed in OMS operation for performing single or multiple burns throughout the mission.

The options available for utilization of the OMS imposes significant requirements for full consumables management capability in order to provide assistance to the crew in employing the OMS remaining delta-velocity capability in an effective manner.

The mandatory requirement for the OMS to provide deorbit delta-velocity capability makes management of OMS propellant essential. Propellant monitoring is provided and data are presented for display in terms of : delta-velocity remaining, and propellant quantities are compared to mission

requirements to the end of mission. Both manual and automatic replanning capability is provided to facilitate evaluating mission revisions. The proposed concept is similar to General Concept Number 1.

Reaction Control System (RCS). Propulsive thrust for attitude control and small delta-velocity translational maneuvers is provided by the RCS which employs nitrogen tetroxide and monomethyl hydrazine as consumables.

The RCS operation is, like the OMS, capable of being utilized in such a manner as to effectively manage consumables usage. Therefore, appreciable onboard capability is proposed to assist the crew in use of the RCS consumables. Maneuver magnitudes and rates, and attitude hold dead bands are factors which influence RCS propellant usage and which may be used to control usage. The proposed consumables management system will provide monitoring and evaluation capability to determine the status of consumables relative to planned values and also to predict consumables requirements for mission revisions. Both manual and automatic replanning capability is provided which makes this management technique similar to General Concept Number 1.

5.6 ADVANCED CONCEPT FEATURES

This study was not limited to features of consumables management which are directly applicable to the Shuttle. However, those capabilities which did not appear acceptable for Shuttle application at the present time were given a low priority. As a result these capabilities were not incorporated in the proposed concepts.

Some of the features which were considered are described in this section. They should be investigated for application to more advanced programs or later phases of the Shuttle program. Implementation of the features to be discussed are technically feasible for performing consumables management with minimal requirements for crew interaction with the system. However, other software and hardware interfaces would be required to provide advanced capability in order to support the consumables management activities. In addition to the advanced concept some of the interface requirements are also discussed.

Consumables Planning - The consumables management system should be capable of processing a mission plan to generate a premission consumables budget and usage profile for each consumable. Included in the budget data would be parameters to define the prelaunch consumables loading requirements. The consumables management system would need these parameters to verify the proper loading of consumables as part of the prelaunch checkout. The usage profiles generated by the consumables management software would serve as references for comparison with actual usage data until such time that new profiles were generated as a result of mission revisions.

Monitoring - In addition to monitoring consumables quantities and usage rates as proposed, additional related subsystem parameters should be monitored and correlation techniques applied to them to assure data accuracy and validity. Such integrated monitoring techniques could be used to provide better information regarding subsystem performance, as well as consumables usage data, and could probably be accomplished with fewer sensors than would be required for performing the two jobs separately.

System Configuration Monitoring - Switch positions and subsystem signals provide indications of subsystem configuration status at any time during the mission. The actual configuration would be tested against the configuration called for by the mission plan and a communication of discrepancies would be made to the crew. Crew selection of an automatic configuration mode would result in the subsystems being configured according to the mission plan without crew action.

The consumables management system would use the subsystem configuration status data to change the software models to agree with actual subsystem indications. Prediction of consumables usage would be then performed and, if excessive usage would result from the current configuration, the crew would be so informed.

Event Detection Monitoring - A majority of the mission events which influence consumables usage can be sensed by monitoring appropriate signals, or combinations of signals, for event detection. These event detection indicators would be used to improve the ability of the consumables management software to aid the crew by indicating the occurrence of unscheduled

events, or nonoccurrence of scheduled events, which would provide information to the crew in assessing the source of constraint violation indications. Without this type of display indication, the crew would simply be informed that a consumable constraint violation had occurred. The crewmen must then follow a diagnostic process to ascertain the source of the deviation.

Constraint Tests - Constraint tests would be utilized to do more than just perform limit checks as is presently proposed for the Shuttle concept. The type of constraint violated would determine subsequent action taken.

One class of constraint violations would result in immediately alerting the crew that a problem has been detected and corrective action would be initiated automatically if the problem warrants such action. An example of this type of constraint would be the violation of a consumable redline value. An immediate violation would be displayed to the crew and automatic subsystem reconfiguration would be initiated to conserve consumables.

A less severe type of constraint violation would issue a caution announcement to the crew to show that a problem may be imminent. A violation which produces a caution would result in a delay of any further action for a predetermined period of time in order to allow some time for the situation to correct itself. An uncorrected caution would eventually precipitate issuance of an alert to the crew and, if warranted, corrective action would be automatically initiated. An example of a caution situation would be the previously described situation where a constraint violation is caused by an event occurring at a slightly different time than scheduled. In such a case, the consumable parameter comparisons might indicate excessive deviation of actual from predicted values, and at the same time, the event detection monitor would show a discrepancy between actual and scheduled events. The appropriate action would probably be to wait a short time and see if the event actually occurs close to the scheduled time. If the event occurs during the specified delay period, the constraint violation indication would go away; if not, further action would be taken to alert the crew of an event discrepancy.

This assignment of priority classification constraint violations would result in fewer nuisance alerts being indicated to the crew.

Performance Tests - In many cases, it is possible to relate consumables usage to subsystem performance as a means of evaluating either the subsystem or consumables management system performance. For example, the oxygen flow rate into a fuel cell is directly proportional to output current. An off-nominal ratio of output current to oxygen flow rate will indicate that a problem exists, even though both the flow rate and current are within constraint limits, and subsequent diagnostic procedures may be required.

Two important uses would result from the performance tests. First, detection of off-nominal subsystem performance would allow the crew to attempt to initiate corrective action to minimize or correct the source of the discrepancy. Second, actual subsystem performance data would be used to improve the software models used within the consumables management system. This technique of adaptive modeling would assure that the consumables usage predictions were based on actual, rather than nominal, subsystem performance. Use of this feature would virtually eliminate one of the potentially large sources of error in the consumables management process.

Control Functions - Automatic activities have been discussed under several of the preceding headings. For completeness, they will be presented briefly in this paragraph to indicate those control functions which, by crew selection of automatic modes, may be used to assist the crew in performing consumables management related functions.

Automatic configuration of subsystems may be accomplished for scheduled events by automatically positioning switches in accordance with switch lists stored in the data base. This automatic action would reduce the crew workload and also reduce the probability of human error which is always present when manual switching is employed.

Violations of important constraints, such as redlines or certain parameter limits, would result in automatic action to prevent further degradation of a problem. Typical action might be to power down all non-essential activities related to the consumables or subsystem indicating the violation. Further use of the subsystem under such a condition would require deliberate crew action to override the automatic function.

6. FUNCTIONAL REQUIREMENTS

Functional requirements were developed to describe the capabilities required for the proposed Shuttle onboard consumables management system. Requirements are specified for the functions of the consumables management software and the interfacing hardware and software and the interfacing hardware and software systems.

6.1 GENERAL CONSUMABLES MANAGEMENT SYSTEM FUNCTIONAL REQUIREMENTS

6.1.1 Design Goal

- a) The consumables management system shall incorporate maximum utilization of the onboard computing facility and the ground support facilities in order to provide the required crew support for performing the consumables management functions. The consumables management functions performed onboard shall include evaluation of premission consumables requirements analysis, monitoring of consumables status, prediction of consumables reserves, and evaluation of consumables requirements for proposed inflight mission plan revisions.
- b) The consumables management system shall provide for a high degree of onboard capability in order to 1.) minimize the requirement for extensive ground support, 2.) increase mission flexibility by facilitating revision of consumables usage plans, and 3.) assure that adequate consumables are available at any point in the mission to proceed according to the accepted mission plan.

6.1.2 Launch Readiness Checkout and Monitoring

- a) The consumables management system shall be capable of verification of compatibility of the mission plan and actual loaded consumable quantities within TBD minutes after completion of vehicle consumables loading operations.
- b) The consumables management system shall be capable of issuing an alert to the ground support complex upon detection of insufficient consumables loading to support the mission plan.

6.1.3 Onboard Mission Operation Support

- a) The consumables management system shall provide the capability to reinitialize consumables usage predictions to coincide with actual consumables status at any time during the mission.
- b) The consumables management system shall provide the capability to analyze and evaluate the impact of inflight mission revision on consumables usage. This capability shall include generation of predicted consumables usage profiles and computation of predicted end-of-mission reserves in order to assist the crew in evaluating mission revisions.
- c) The consumables management system shall provide the capability to activate a crew alert upon detection of a violation of limit values on actual or predicted parameters. Sufficient information shall be provided about the limit violation to allow for initiation of crew and/or ground assessment of appropriate corrective action.

6.2 AUXILIARY POWER UNIT (APU) CONSUMABLE MANAGEMENT FUNCTIONAL REQUIREMENTS

6.2.1 Design Goal

- a) The consumables management system shall provide monitoring capability for determining APU consumables status.
- b) The consumables management software shall provide onboard capability for performing leak detection functions.

6.2.2 Launch Readiness Checkout and Monitoring

- a) Consumables management software shall provide for accepting and storing ground supplied APU consumables requirements, usage profiles, and parameter limit value data.
- b) Consumables management software shall be capable of verifying compatibility between mission APU consumables requirements and actual loaded quantities within TBD minutes after completion of APU consumables loading operations.
- c) Consumables management software shall be capable of issuing a ground alert upon detection of insufficient APU consumables to support the mission plan.

6.2.3 Onboard Mission Operation Support

- a) The consumables management system shall provide for monitoring and displaying APU consumables quantity and usage rates data for hydrazine and cooling water for all APU's. The capability shall be provided to project leakage rates to the end-of-mission in order to determine the time that redline violations will occur.
- b) Consumables management software shall provide the capability to check indicated quantities and leakage rates against limit values. Limit values may be variable functions of mission elapsed time.
- c) Consumables management software shall provide the capability to activate a crew alert upon determining that APU consumables parameters have violated a limit value. The software shall provide APU consumables data for display to the crew in order to aid in assessing the cause of a violation and the appropriate course of action.

6.3 ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM (ECLSS) CONSUMABLE MANAGEMENT FUNCTIONAL REQUIREMENTS

6.3.1 Design Goal

- a) The consumables management system shall provide monitoring of ECLSS consumables quantities and usage rates, evaluation of actual consumables usage compared to predictions supplied from both preflight ground analysis and inflight updates, and testing consumables parameters for constraint violations.
- b) Consumables management software shall provide for a high degree of onboard capability to accomplish ECLSS consumables management functions without requirements for extensive ground support during flight operations.

6.3.2 Launch Readiness Checkout and Monitoring

- a) The consumables management software shall provide for accepting and storing ground supplied usage profiles and defined limit value data for ECLSS oxygen, nitrogen, ammonia, water, lithium hydroxide, and biocide.
- b) The consumables management system shall be capable of verifying compatibility between predicted and actual loaded quantities of ECLSS nitrogen, ammonia, lithium hydroxide, water, and biocide within TBD minutes after completion of ECLSS loading operations.

- c) Consumables management software shall be capable of issuing a ground alert upon detection of insufficient ECLSS consumables quantities to support the mission plan.

6.3.3 Onboard Mission Operations Support

- a) The consumables management system shall provide the capability for onboard monitoring of ECLSS consumables status. Monitoring capability shall include nitrogen, ammonia, water, lithium hydroxide, and biocide quantities available and shall also include the capability to determine usage rates for ECLSS oxygen, nitrogen, ammonia, water, lithium hydroxide, and biocide.
- b) Consumables management software shall provide inflight capability to predict end-of-mission reserves for nitrogen, lithium hydroxide, ammonia, and biocide.
- c) Consumables management software shall provide the capability to reinitialize ECLSS consumables prediction to coincide with actual consumables status at any time during the mission.
- d) Consumables management software shall provide the capability for analysis and evaluation of mission revision impact on usage requirements for ECLSS oxygen, nitrogen, ammonia, lithium hydroxide, and biocide. Consumables management software shall provide for analysis and evaluation of mission revisions initiated by either crew supplied manual inputs or computer supplied automatic inputs, and shall include capability for generation of revised cryogen usage profiles and for revised prediction of end-of-mission reserves.
- e) Consumables management software shall provide the capability to predict total ECLSS oxygen requirements to the end-of-mission. The ECLSS oxygen requirement predictions will be provided for use in management of the Cryogenic Storage System consumables.
- f) Consumables management software shall provide the capability to predict time at which ECLSS water quantities will reach upper and lower limit values to assist in determining dump and sublimation periods.
- g) Consumables management software shall provide the capability to activate a crew alert upon determining that ECLSS consumables status parameters have violated defined limit values or that violations are predicted to occur for ECLSS oxygen, nitrogen, ammonia, lithium hydroxide, and biocide. The capability shall be provided to determine the time that redline violations

are predicted to occur. Capability shall be provided to display pertinent ECLSS consumables data to the crew in order to aid in assessing the cause of a violation and the appropriate course of action.

- h) Consumables management software shall provide information as to the number of lithium hydroxide cannisters available at any time during the mission. Lithium hydroxide cannister change out indications must be provided by crew supplied manual inputs.

6.4 FUEL CELL AND CRYOGENIC STORAGE (FCCS) CONSUMABLES MANAGEMENT FUNCTIONAL REQUIREMENTS

6.4.1 Design Goal

- a) The consumables management system shall provide the capability for monitoring of FCCS cryogen quantities and usage rates, determining and evaluating premission cryogen usage predictions, evaluating cryogen requirements for inflight mission plan revisions, and testing consumables parameters for constraint violations.
- b) Consumables management software shall provide for a high degree of onboard capability to accomplish FCCS consumables management functions without requirement for extensive ground support during flight operations.

6.4.2 Launch Readiness Checkout and Monitoring

- a) The consumables management software shall provide the capability for processing a ground supplied mission plan in order to provide premission generation and analysis of FCCS cryogenic hydrogen and oxygen usage profiles, calculation of predicted cryogenic hydrogen and oxygen quantities required, and calculation of predicted end-of-mission reserves.
- b) The consumables management system shall be capable of verifying compatibility between predicted and actual loaded quantities of FCCS cryogenic hydrogen and oxygen within TBD minutes after completion of FCCS loading operations.
- c) Consumables management software shall be capable of issuing a ground alert upon detection of insufficient FCCS consumables quantities to support the mission plan.

6.4.3 Onboard Mission Operations Support

- a) The consumables management system shall provide the capability for onboard monitoring of FCCS consumables status. Monitoring capability shall include cryogenic hydrogen and oxygen quantities and usage rates. Capability shall be provided for hydrogen and oxygen tank balance calculations and evaluation.
- b) Consumables management software shall provide inflight capability to predict end-of-mission reserves for FCCS cryogenic hydrogen and oxygen. Capability shall be provided for accepting and including predicted ECLSS oxygen requirements in the FCCS oxygen requirements in the FCCS oxygen requirement predictions.
- c) Consumables management software shall provide the capability to reinitialize FCCS cryogen usage predictions to coincide with actual consumables status at any time during the mission.
- d) Consumable management software shall provide the capability for analysis and evaluation of mission revision impact on FCCS cryogen usage capability shall be provided for analysis and evaluation of mission revisions initiated by either crew supplied manual inputs or computer supplied automatic inputs, and shall include capability for generation of revised cryogen usage profiles and for revised prediction of end-of-mission reserves.
- e) Consumables management software shall provide the capability to activate a crew alert upon determining that either cryogenic hydrogen or oxygen status parameters have violated defined limit values or that violations are predicted to occur. Capability shall be provided to determine the time that redline violations are predicted to occur. Capability shall be provided to display pertinent FCCS consumables data to the crew in order to aid in assessing the cause of a constraint violation and the appropriate course of action.

6.5 MAIN PROPULSION SYSTEM/EXTERNAL TANKS (MPS/ET) CONSUMABLES MANAGEMENT FUNCTIONAL REQUIREMENTS

6.5.1 Design Goal

- a) The consumables management system shall provide the capability for calculating the remaining delta-velocity capability and the delta-velocity residual provided by the MPS/ET propellant.

6.5.2 Launch Readiness Checkout and Monitoring

- a) The consumables management software shall provide the capability for accepting and storing ground supplied MPS/ET propellant requirements remaining delta-velocity profiles and parameter limit value data.
- b) The consumables management system shall be capable of verifying that sufficient MPS/ET propellant is loaded to support the planned mission. Verification shall be capable of being performed within TBD minutes after completion of ET loading operations.
- c) Consumables management software shall be capable of issuing a ground alert upon detection of insufficient MPS/ET propellant to support the mission plan.

6.5.3 Onboard Mission Operations Support

- a) The consumables management system shall provide the capability for onboard monitoring and display of remaining delta-velocity and delta-velocity residual values.
- b) Consumables management software shall provide capability for accepting propellant flow rate data from the avionics systems.
- c) Consumables management software shall provide capability to activate a crew alert upon detection of violation of defined limit values placed upon delta-velocity residuals and difference between actual and predicted remaining delta-velocity.

6.6 REACTION CONTROL SYSTEM/ORBITAL MANEUVERING SYSTEM (RCS/OMS) CONSUMABLES MANAGEMENT FUNCTIONAL REQUIREMENTS

6.6.1 Design Goal

- a) The consumables management system shall provide capability for monitoring of RCS/OMS propellant quantities, determining and evaluating premission RCS/OMS propellant usage predictions, evaluating RCS/OMS propellant requirements for in-flight mission plan revisions, and testing consumables parameters for constraint violations.
- b) Consumables management software shall provide for a high degree of onboard capability to accomplish RCS/OMS consumables management functions without requirement for extensive ground support during flight operations.

6.6.2 Launch Readiness Checkout and Monitoring

- a) The consumables management software shall provide the capability for processing a ground supplied mission plan in order to provide premission generation and analysis of RCS and OMS propellant usage profiles, calculation of total RCS and OMS propellant quantities required, calculation of RCS mixture ratio outage, and calculation of RCS and OMS propellant end-of-mission reserves.
- b) The consumables management system shall be capable of verifying compatibility between predicted and actual loaded quantities of RCS and OMS propellants within TBD minutes after completion of propellant loading operations.
- c) Consumables management software shall be capable of issuing a ground alert upon detection of insufficient quantities of either RCS or OMS propellants to support the mission plan.

6.6.3 Onboard Mission Operations Support

- a) The consumables management system shall provide the capability for onboard monitoring of RCS and OMS propellant quantities and for inflight calculation of RCS mixture ratio outage using actual RCS fuel and oxidizer quantities used and remaining. Capability shall be provided for performing RCS tank balance calculation and evaluation.
- b) Consumables management software shall provide capability to predict end-of-mission reserves for both RCS and OMS propellants.
- c) Consumables management software shall provide capability to reinitialize RCS propellant usage predictions to coincide with actual consumables status at any time during the mission.
- d) Consumables management software shall provide capability for analysis and evaluation of mission revision impact on RCS and OMS propellant requirements. Capability shall be provided for analysis and evaluation of mission revisions initiated by either crew supplied manual inputs or computer supplied automatic inputs, and shall include capability for generation of revised RCS propellant usage profiles and for revised prediction of RCS and OMS propellant end-of-mission reserves.
- e) Consumables management software shall provide the capability to activate a crew alert upon determining that either the RCS or OMS propellant status parameters have violated defined limit values or that violations are predicted to

occur. Capability shall be provided to determine the time that limit value violations are predicted to occur. Capability shall be provided to display pertinent RCS/OMS consumables data to the crew in order to aid in assessing the course of a constraint violation and the appropriate course of action.

6.7 CONSUMABLES MANAGEMENT SYSTEM/ORBITER AVIONICS SYSTEMS FUNCTIONAL REQUIREMENTS

6.7.1 Mission Data Information Management

- a) The orbiter avionics system shall provide the capability for processing a ground supplied mission activity timeline into consumable event timelines.
- b) The orbiter avionics system shall provide the capability for generation or acceptance of ground supplied mission specific data.
- c) The orbiter avionics system shall provide the capability to distribute all consumables constraints data, expected consumable loading data, consumables event timelines and mission specific data to the consumables management software.

6.7.2 Ground Command and Data Link Interface

- a) The orbiter avionics system shall provide the capability for ground support system interface and control of consumables management software during both ground and inflight operations.
- b) The orbiter avionics system shall provide the capability for ground monitoring of consumables management software output data during both ground and inflight operations.

6.7.3 Display and Control

- a) The orbiter avionics system shall provide the capability for alerting the crew of consumables management software indications of constraint violations.
- b) The orbiter avionics system shall provide the capability for crew interaction with the consumables management software. This capability shall include crew manual inputs to enter revised mission activity timeline data and specific revised consumable management software constants.
- c) The orbiter avionics system shall provide the capability for formatting and generating consumables management system CRT displays.

6.7.4 Data Processing and Software Support

- a) The orbiter avionics system shall provide the computational facilities for the consumables management software.
- b) The orbiter avionics system shall provide TBD computer words of storage for the consumables management software.
- c) The orbiter avionics system shall provide for scratch memory storage and CRT display of interim consumables management software calculations.

6.7.5 Instrumentation Software

- a) The orbiter avionics system shall provide capability for sampling, conditioning, storing, and distributing of subsystem consumable data to the consumables management software.
- b) The orbiter shall provide mission time data to the consumable management software.

6.7.6 Guidance Navigation and Control Software

- a) The orbiter avionics system shall be capable of supplying specified guidance, navigation and control parameters to the consumables management software.
- b) The orbiter avionics system shall provide the capability to update and revise the mission activity timeline directly from guidance, navigation and control software calculations for specific types of mission revisions.

6.8 CONSUMABLES MANAGEMENT SYSTEM/GROUND SUPPORT SYSTEM FUNCTIONAL REQUIREMENTS

6.8.1 Ground Mission Operation Support

- a) The ground support system shall provide premission planning data which shall include preparation of the mission activity timeline, consumables management software constants, consumables management constraints data, and predicted consumables usage profiles.
- b) The ground support system shall provide real-time consumables management analysis and evaluation data to support flight operations.

- c) The ground support system shall provide real-time consumables management support for updating consumables management software constants, consumables management constraints data, and mission activity timeline data.
- d) The ground support system shall provide the capability for real-time consumables management mission planning. This capability shall provide prime support for TBD consumable systems and back up support for TBD consumable systems.
- e) The ground support system shall provide the capability for post flight analysis and evaluation of consumables usage and subsystems performance data in order to revise the consumables management software model constants for improving consumables usage prediction accuracy.

7. STUDY LIMITATIONS

The major emphasis of this study was placed on development of consumables management techniques which are directly applicable for the Shuttle Program. For this reason, the concepts developed and the operational features proposed are limited to techniques which are presently available and feasible for Shuttle applications.

The degree of detail of portions of the study are limited because information was not yet available to define subsystem design features and operational procedures which impact the Shuttle consumables management system. The general study results are valid even though some specific features of the techniques for implementing the subsystem consumables management software will probably change as better design information becomes available.

8. RELATIONSHIP TO OTHER EFFORTS

Consumables management is related to flight operations throughout the various phases from preliminary mission design through postflight analysis as is illustrated in Figure 8-1. In regard to this study, the related areas of immediate importance are the current developmental activities involving direct interfaces with the onboard consumables management system. Included in this category is the facility which produces the ground supplied consumables mission planning data and the onboard facility for providing subsystems performance data.

The importance of the relationship between the facility which supplies the mission dependent onboard software data and the consumables management software is primarily due to two factors. First, the consumables management requirements which define the content and format of the ground supplied data should be developed to be consistent with other similar types of data in order to avoid generating unique requirements unnecessarily. Second, the performance accuracy of the consumables management system is a function of the fidelity of the ground supplied input data which describes the mission events and activities. Therefore, the data content must be well understood in order to assure that it is properly utilized by the onboard consumables management software.

Subsystems performance data provided by the onboard monitoring system is utilized in conjunction with consumables management activities. Similarities in the data requirements and the data acquisition and display techniques for the two systems necessitates that development of the two activities be closely related. In addition, the inflight operation will result in mutually beneficial information being provided for correlating subsystems performance and consumables usage.

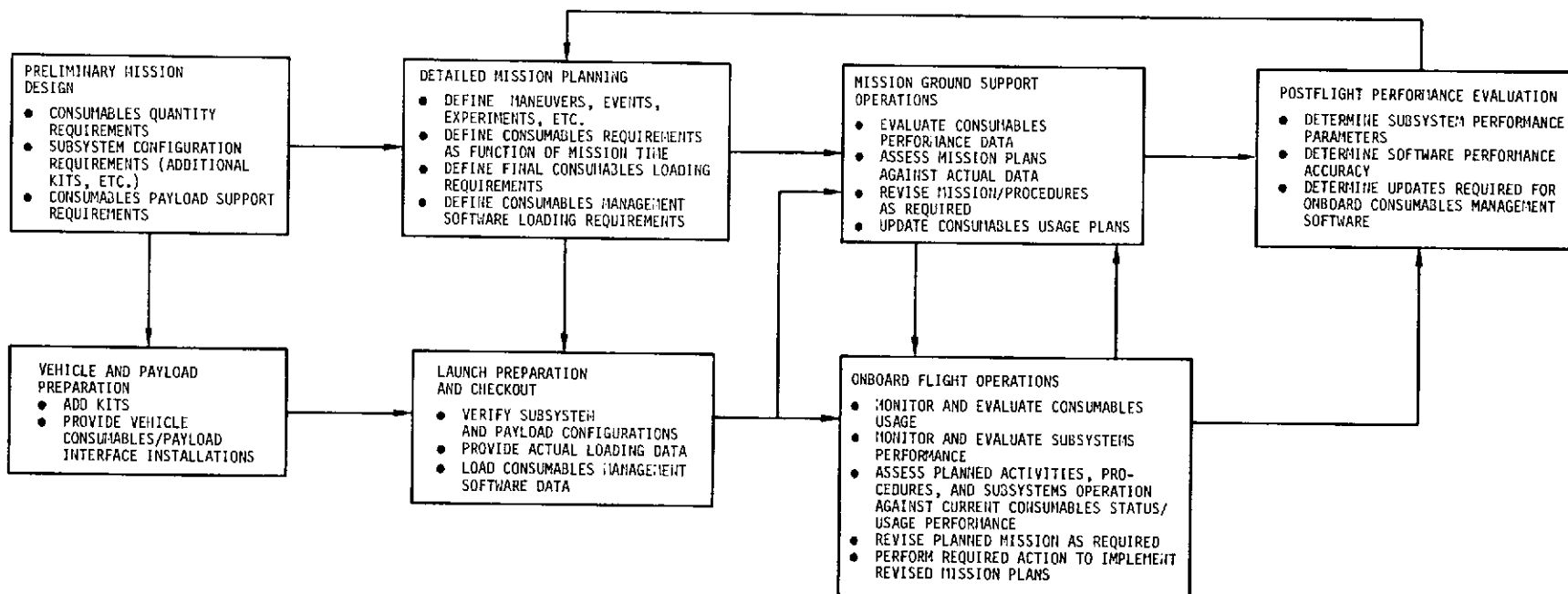


Figure 8-1 Relationship of Consumables Management to Various Flight Operations Phases

9. SUGGESTED ADDITIONAL EFFORT

9.1 GROUND SYSTEMS SUPPORT

Assumptions have been made during this study as to the ground support capability to provide information to operate successfully with the proposed onboard system. Further study should be made to verify that the information generated by the ground system is in a form which is compatible with the onboard system.

9.2 DATA EDITING TECHNIQUES

Software techniques are needed to perform data editing of the subsystem sensor measurements. Studies should be made to determine techniques which are generally applicable to sensor signals and which minimize the total software required to perform the editing functions. Editing should perform two functions: 1) false alarm avoidance by elimination of extraneous data, and 2) statistical averaging to assure that trending data selected for storage is indicative of true performance.

10. REFERENCES

1. H. A. Herwig, "Consumables Management Study Phase I-Apollo Review," TRW IOC 72:7153.5-199, 28 September 1972.
2. P. J. Graf, "Meeting with C-5 Systems Manager Technical Services, Kelly AFB, San Antonio," TRW IOC 72-6531.5-15, 10 August 1972.
3. P. J. Graf, "Trip Report - Continental Airlines, Los Angeles, California," TRW IOC 72.5431.5-19, 26 September 1972.
4. P. J. Graf, "Airline Consumables Management Review," TRW IOC 72.6531.5-20, 26 September 1972.
5. L. W. Neel, "First Quarterly Progress Report for Contract NAS 9-12944," 10 November 1972.
6. P. J. Graf, "Shuttle Consumables Management Concept," TRW Letter 6531.10-73-51, 16 May 1973.
7. L. W. Neel, "Second Quarterly Progress Report for Contract NAS 9-12944," 8 March 1973.
8. H. A. Herwig, "Software/Crew Display Interface Definition for Onboard Consumable Management," TRW Letter 6530.4-044, 26 July 1973.